PAKISTAN CHEST SOCIETY
STRIVING FOR PULMONARY CARE

Preoperative Pulmonary Risk Assessment Guidelines

A National Clinical Guideline (2020)

Pakistan Chest Society

GUIDELINES FOR THE

Preoperative Pulmonary Risk Assessment

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PAKISTAN CHEST SOCIETY

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Message By The President Pakistan Chest Society (PCS)

The Pulmonologist are involved in the management of patients undergoing major surgical procedures and they are providing crucial guiding role in the perioperative management of the patients undergoing various surgical procedures with respect to respiratory therapy. Pakistan Chest Society while assessing the requirement of guidelines on different subjects for reference, among others it was decided to prepare a guideline on Preoperative risk assessment.

The goal in publishing these guidelines has always been to provide a resource that can serve as guide for postgraduate residents and clinicians who choose to embark on this educational journey. Postgraduates and junior doctors have treasures of knowledge just it needs to let them know how to apply such knowledge in systematic and organized way.

It is the hard work of the guideline working group which has put lot of effort, time and energy in bringing this guideline in your hand. For their dedicated effort I would like to congratulate them without which it would not been possible to have this first ever guideline on this subject in Pakistan. The topics selected in this guideline are comprehensive and encompassing all essential and crucial aspects of application of pulmonary medicines protocols in pre-operative pulmonary risk assessment of those patients who are planned to undergo surgical interventions. This guideline will definitively help postgraduate trainees, Pulmonologist, Physicians and those involved in the management of surgical patients.

Professor Nisar Ahmed Rao

President Pakistan Chest Society

Message By The Chairman Guidelines Committee, Pakistan Chest Society (PCS)

It is a matter of great pleasure, pride and satisfaction that the first guideline for the **Preoperative Pulmonary Risk Assessment Guidelines** has been published by PCS**.** Governing Council of PCS has mandated the Guideline committee to develop evidence based guidelines for important pulmonary diseases. Besides this document, guidelines on Asthma, Sleep apnea, Noninvasive ventilation, COPD and guideline on smoking Cessation have already been developed and will distributed during the 14^{th} Biennial Chest Con 2020 in Karachi. It is very encouraging to note that PCS has been consistently working on developing and updating guidelines. These guidelines provide a highly valuable resource for the trainees and practicing physicians.

Postoperative pulmonary complications (PPCs) are common complications that increase morbidity and mortality rates after surgery, particularly among patients with pulmonary conditions. Therefore, efforts to stratify the risk for PPCs and implement strategies to reduce these risks will improve patient outcomes. This guideline provides a current & updated information available in the area of preoperative risk management. This guideline provides a highly valuable resource for the trainees and practicing physicians involve in perioperative medicine.

Finally, I would like to acknowledge the hard work of Dr Masooma and other members of the working group who has prepared this very informative document and the members of PCS guideline committee for reviewing the document. PCS remain committed to always endeavor for the achievement of the best possible clinical practice.

Prof. Muhammad Irfan

Chairman Guidelines Committee, PCS

Preface

Comprehensive preoperative risk stratification is of an increasing significance in today's clinical medicine. The type and range of invasive procedures/diagnostic testing offered in various subspecialties has exponentially increased over recent decades. Subsequently, there is an increased need to provide efficient and safe perioperative care for patients.

Effective risk assessment hinges on a balance between avoiding unnecessary testing that delays potentially beneficial surgery, yet also accurately identifying high-risk patients, in whom measures can be taken to mitigate perioperative risk.

Validated preoperative cardiac risk assessment tools have been widely used for some time now. But preoperative pulmonary risk assessment has often rested on bedside clinical gestalt. This practice is now set to change with newer pulmonary risk assessment tools being validated in larger populations of patients internationally.

By formulating these clinical guidelines, we want to disseminate the current & updated information available in the area of preoperative risk management. Much of this is based on internationally published work and there is a great need for our own local literature to populate this area as well.

We hope that this guideline will provide a comprehensive, informative review for all clinicians involved in perioperative medicine.

Masooma Aqeel, MD

Contents

Executive summary

Definitions and Risk Factors for PPCs

- **The term post-operative pulmonary complication (PPC) encompasses essentially any complication that affects the respiratory system after patients have undergone surgery and anaesthesia. Incidence of PPCs after major surgery is highly variable**

- **PPCs are more common than cardiac complications in patients undergoing non cardiac surgeries and are associated with longer hospitalization, higher morbidity and mortality**

- **Several important changes in pulmonary physiology take place during induction and in the pre- and postoperative period. These include a reduction in functional residual capacity, development of atelectasis, impairment of upper pharyngeal reflexes and in general a decreased ability to increase ventilation in response to hypoxemia or hypercapnia**

- **Patient related risk factors such as age > 50 years, partial or total functional dependence, obstructive sleep apnea, obesity, cigarette smoking, presence of chronic obstructive pulmonary disease (COPD), uncontrolled asthma, pulmonary hypertension, heart failure tends to increase risk for post-operative pulmonary complications**

- **Smoking cessation for > 5-8 weeks prior to surgery tends to confer some advantage in reducing PPCs risk versus those who continue smoking up to 2 weeks of surgery**

- **Procedure related risk factors that increase risk for PPCs include site of surgery (upper abdominal and thoracic conferring the highest risk), use of general anesthesia, length of surgery (generally if > 2-3 hours) and use of neuromuscular blockade**

Pre-operative Assessment

- **A complete history and physical examination are essential for detecting, and potentially modifying, significant risk factors (unexplained cough dyspnoea etc.)**
- **Preoperative pulmonary function testing aims to a) identify those in whom the benefits of surgery do not outweigh the risks and b) identification of those who are at a high risk and in whom modification of risk factors via an aggressive preoperative approach is warranted**
- **Patient undergoing thoracic surgery (particularly coronary artery bypass grafting or lung resection) consistently benefit from preoperative pulmonary function testing**
- **Spirometry does not appear to add any additional predictive value to information available from preoperative history & clinical examination and is not routinely recommended for patients undergoing extra thoracic surgery**
- **Current data does not support the use of routine preoperative arterial blood gas measurements to stratify patients for risk of PPCs**
- **Current data does not support routine preoperative chest radiography in most patients. It is considered reasonable to perform chest x-rays in patients who have known cardiopulmonary disease or those who are > 50 years of age and undergoing high risk surgical procedures such as upper abdominal, aortic, esophageal or thoracic surgery**
- **Patients with lung cancer should undergo pulmonary function testing to determine candidacy for operability (lung cancer resection surgery). FEV1 and DLCO measurements > 80% predicted generally indicate ability to tolerate extensive surgery including pneumonectomy and these patients do not need further evaluation**
- **Patients with FEV1 and/or DLCO < 80% should undergo estimation of their postoperative FEV1 or DLCO. PPO FEV1 or PPO DLCO <40% generally indicates patients at high risk for PPCs and mortality. Patients with PPO FEV1 or PPO DLCO > 40% but <80% may benefit from undergoing additional testing such as stair climb or cardiopulmonary exercise testing (CPET) to further determine their risk for post-operative complications**
- **Several validated clinical risk scoring systems have now been developed based on data from large cohorts of patients to enable estimation of individual preoperative risk. These include the Canet risk index, the Arozullah and the Gupta scoring systems**

Risk Reduction: Recommended strategies to reduce PPCs

- **Preoperative smoking cessation is associated with favorable postoperative outcomes. Abstinence period should be 8 weeks or more, where possible before proceeding for elective surgery. Patients should receive behavioral and pharmacological support for smoking cessation as the preoperative period can be highly effective for the smoking cessation attempt**

- **Patients with signs and symptoms of upper respiratory tract infections should be treated first before proceeding for elective surgery**

- **Pulmonary rehabilitation and breathing exercises should be started in the preoperative period**

- **Prefer neuraxial (spinal/epidural) anesthesia to general anesthesia (where feasible), particularly in a high-risk population. Shorter acting neuromuscular blocking agents are preferred over longer acting agents and a complete reversal of neuromuscular blockade at the end of surgery is imperative**

- **Utilize lung protective ventilator strategy intra-operatively**

- **Use fluids judiciously intra and postoperatively to avoid the risk of pulmonary edema and lung injury**

- **Early mobilization, adequately controlled pain is associated and better adherence to breathing exercises is shown to reduce risk for PPCs**

- **Post-operative VTE prophylaxis should be administered in all patients to prevent VTE (based on the estimated postoperative risk of bleeding)**

Optimization of underlying pulmonary diseases

- **Well-controlled asthma poses no additional risk for PPCs. However, patients with poorly controlled asthma should be optimized prior to proceeding for surgery. Regular treatment of asthma including ICS/LABA and as needed reliever medications should be continued in the preoperative and postoperative period**

- **Stress dose steroids are indicated in patients deemed at risk of hypothalamic-pituitary adrenal suppression**

- **COPD patients with symptoms or with limitation in exercise should be treated aggressively preoperatively to achieve stable baseline status**

- **NIPPV or non- invasive ventilation is recommended for weaning from mechanical ventilation**

- **Patients with obstructive sleep apnea should use their device during the perioperative period. Non-compliant OSA patients should be encouraged to use their PAP devices to optimize their comorbids**

- **In patients who are undiagnosed but deemed at high risk to have OSA, the decision to proceed for surgery should depend on the urgency of the procedure, perceived severity of OSA and control of associated comorbidities**

- **Patients should be extubated when fully awake and after the reversal of effects neuromuscular blocking agents. Opioids should be avoided where possible**

- **Preoperative evaluation and management of patients with pulmonary hypertension requires a multidisciplinary team including pulmonary/critical care, cardiology, surgery and anesthesiology**

- **Patients with underlying pulmonary hypertension should be optimized medically prior to surgery. Factors that may precipitate or worsen pulmonary artery pressure or pulmonary vascular resistance (PVR) (such as volume overload, over ventilation, under-treated pain) should be avoided**

- **Patients with restrictive lung disease should undergo a careful risk versus benefit discussion that includes a discussion around risk for prolonged mechanical ventilation, risk for PPCs, mortality, benefits of the procedure and alternative treatment options, prior to proceeding with surgery**

Section I: Introduction

A. Definition of Post-Operative Pulmonary Complications (PPCs)

The term post-operative pulmonary complication (PPC) encompasses essentially any complication that affects the respiratory system after patients have undergone surgery and anaesthesia[1]. These complications occur commonly, are difficult to predict and can lead to adverse outcomes.

Definitions of a PPCs vary considerably making it difficult to quantify a precise incidence. According to the European Perioperative Clinical Outcome (EPCO) definition, PPCs include respiratory infections, respiratory failure requiring non-invasive (NIPPV) or invasive ventilation, pleural effusions, atelectasis, pneumothorax, bronchospasm, aspiration pneumonitis, pneumonia, adult respiratory distress syndrome (ARDS), tracheobronchitis, pulmonary edema, exacerbation of pre-existing lung disease, pulmonary embolism and death (see Table) . Specific post-operative cardiothoracic complications that affect the respiratory system are also considered here and include phrenic nerve injury, thoracic duct injury, pleural effusion, bronchopleural fistula development, sternal wound infection, empyema or gastroesophageal anastomotic leak etc.

Incidence of PPCs after major surgery is variable (reported from < 1% to as high as 80%)[1,3] Studies in patients undergoing non-cardiac surgery reveal that post-operative pulmonary complications are far more common than cardiac complications and are associated with significantly longer hospital stay (22.7 vs 10.4 days, p = 0.001)[8]. In addition, PPCs are associated with a higher rate of intensive care unit (ICU) admission as well as higher post-operative morbidity and mortality. Large scale studies show that both 30-day, and 90-day,mortality rates are higher for those who suffer PPCs (30-day;19.5% vs 0.5% and 90-day; 24.4% vs 1.2%) [1,3,5] Proper identification of risk factors (modifiable and non-modifiable) and prompt action to minimize these risks can help reduce PPCs and associated adverse patient outcomes.

Table. Definitions for post-operative pulmonary complications (PPCs) (adapted[1,2])

Outcome Measure	EPCO definitions	Other published definitions
Respiratory Infection	Antibiotics for suspected infection with ≥ 1 of the following: • New or changed sputum, • New or changed lung opacities, • Fever, • WBC > 12 x 10^9/ L	≥ 2 of the following for48 hours: • New cough/sputum production, • Physical findings compatible with pneumonia, • Fever38˚C, • New infiltrates on CXR
Respiratory Failure	• Postoperative PaO2 <60mm Hg (room air), • PaO2/FIO2 ratio <300mm Hg, • Arterial oxyhemoglobin saturation (SaO2)<90% and requiring oxygen	• Ventilator dependence for >1 POD or re-intubation • Need for postoperative mechanical ventilation >48 hours • Unplanned re-intubation because of respiratory distress, • Hypoxia, hypercarbia, or respiratory acidosis within 30 days of surgery • Re-intubation within 3 days requiring mechanical ventilation • Postoperative acute lung injury, ARDS • Requiring mechanical ventilation within 7 days of surgery or NIV
Pleural Effusion	CXR with blunting of costophrenic angle, loss of sharp silhouette of the ipsilateral hemidiaphragm in upright position , displacement of adjacent anatomical structures	Pleural effusion requiring thoracentesis
Atelectasis	Lung opacification with mediastinal shift, hilum or hemidiaphragm shift towards the affected area, with compensatory hyperinflation in adjacent non-atelectatic lung	Requiring bronchoscopic intervention Major atelectasis (one or more pulmonary segments)
Pneumothorax	Air in the pleural space with no vascular bed surrounding the visceral pleura	Pneumothorax requiring thoracentesis
Bronchospasm	Newly detected expiratory wheeze treated with bronchodilators	Clinical diagnosis resulting in change in therapy. Refractory wheeze requiring IV drugs in addition to preoperative regimen
Pneumonia	CXR with either an infiltrate, consolidation, cavitation, plus at least one of the following: • Fever >38˚C with no other cause, • WBC < 4 or > 12 x 10^{D}/L, • Age>70 years with altered mentation of no other cause, Plus at least two of the following: • New purulent/changed sputum, • Increased secretions/suctioning, • New/worse cough/dyspnea/tachypnoea, rales/bronchial breath sounds or worsening gas exchange	• Radiographic change & antibiotics • Antibiotics with new/changed sputum or radiographic change or fever or increased WBC > 12 x 10^9/ L • Two or more of the following for 2consecutivedays: new cough/sputum production, examination compatible with pneumonia, temperature >38 C and radiographic change • New or progressive infiltrate on CXR or crackles or dullness on percussion and any of the following: new purulent/changed sputum, positive blood cultures, isolation of pathogen from sputum • Positive sputum culture or infiltrate on
		CXR, and diagnosis of pneumonia or pneumonitis • New infiltrate on CXR plus fever, leukocytosis, and positive sputum Gram stain/culture
ARDS		Ventilated, bilateral infiltrates on CXR, PaO2/FIO2 ≤300, minimal evidence of fluid overload within 7 days of surgery
Tracheobronchitis		Purulent sputum with normal chest radiograph
Pulmonary edema		Pulmonary congestion/hypostasis, acute edema of lung, congestive heart failure
Exacerbation of pre-existing lung disease		Not further defined
Pulmonary Embolism		Not further defined
Death		

B. Perioperative Pulmonary Physiology

Changes in respiratory physiology start as early as the induction of anesthesia. General anesthesia causes a dose-dependent reduction in minute ventilation and predisposes to the development of hypercapnia or hypoxemia in the absence of artificial ventilation. Respiratory muscle function changes as the spine develops an increased curvature and a cephalad displacement of the diaphragm causes reduction in the cross-sectional surface area of the thorax. In anesthetized patients (even without the use of neuromuscular blockade (NMBD)), functional residual capacity (FRC) declines by approximately 15-20% from normal awake and supine measurements. This, along with abnormal regional ventilation during intermittent positive pressure ventilation and reduced cardiac output can alter ventilation perfusion relationships

A more significant effect with respect to PPCs is the development of atelectasis. Contributory physiological factors include a direct compression of lung tissue (i.e. by a more cephalad diaphragm), airway closure when functional reserve capacity (FRC) reduces below closing volume and a rapid reabsorption of gases from alveoli in lung regions were the airways are narrowed or closed. The latter mechanism is exacerbated using high inspired oxygen fraction (FiO). Strategies that may be used to minimize atelectasis involve avoiding the use of 100% oxygen and maintaining moderate levels of positive pressure during expiration to maintain airway patency.

Hypoxia is also common in the post anesthesia recovery unit (PACU) and several factors are contributory. For instance, there may be continued respiratory depression from the effect of sedatives and lingering effects of neuromuscular blockade (NMBD) persist even though conventional monitoring and measurement devices indicate complete reversal. Fine control and coordination of the pharyngeal muscles is impaired and results in higher risk for aspiration and

[1].

upper airway obstruction. In addition, there is evidence to suggest that normal ventilatory responses to hypoxemia and hypercapnia are blunted in sedated patients [1].

Restoration of the normal alveolar to arterial oxygen difference may take several days and episodes of hypoxemia may occur intermittently. After upper abdominal surgery, FRC reaches its lowest value 1-2 days after surgery and slowly returns to normal approximately 5-7 days after surgery. Respiratory control may be abnormal for several weeks after anesthesia and surgery (i.e. reduced ventilatory responses to hypoxemia and hypercapnia). This has major implications for overcoming airway obstruction when asleep and explains the problems encountered by patients with obstructive sleep apnea in the peri- and post-operative period[1].

C. Factors Associated with Post-Operative Pulmonary Complications (PPCs)

Several authors have studied the incidence of PPCs in both thoracic and non-thoracic surgery patients. Potential preoperative patient related risk factors include age, smoking history (pack-years), ASA (American Society of Anesthesiologists) physical status grade, pulmonary hypertension, heart failure, COPD. More recently highlighted risk factors include obstructive sleep apnea (OSA) and pulmonary hypertension (PH).

Potential procedure related risk factors described are surgical site (thoracic, upper abdominal etc.), duration and type of anesthesia used, and the use of neuromuscular blockade.

Patient-related Risk Factors

Age

Age has previously been considered a minor but independent predictor for PPCs. Surgery should not be declined in elderly patients who are otherwise deemed acceptable surgical candidates[6].

Studies show that age > 65 years is an independent risk factor for post-operative intensive care admissions[7] . A systematic review including multiple studies stratified patients into age groups of 50-59 years, 60-69 years, 70-79 years and > 80 years and found that the risk for PPCs systematically increases with age when compared with patient < 50 years of age, odds ratio (OR) of 1.50, 2.28, 3.90 and 5.63 respectively[8] . That is to say, age > 50 years increases risk for PPCs.

Health status

Functional dependence defined as total dependence (inability to perform any activities of daily living) and partial dependence (defined as the need for equipment or devices and assistance from another person) both are associated with an increased risk for PPCs, OR 2.51 and 1.65, respectively. Impaired sensorium (defined as an acutely delirious patient or those with mental status changes in the context of current illness) also increases risk for PPCs, OR 1.39. Similarly, ASA classification of II or greater, significantly increases risk for PPCs, OR 4.87. ASA scoring is described here[8].

Table. American Society of Anesthesia (ASA) Clinical Score

AMERICAN SOCIETY OF ANAESTHESIA (ASA) CLINICAL SCORE	
ASA I	A normal healthy patient, no systemic disorder
ASA II	A patient with mild systemic disease
ASAIII	A patient with severe systemic disease
ASA IV	A patient with severe systemic disease that is a constant threat to life
ASA V	A moribund patient who is not expected to survive without the operation
ASA VI	A declared brain-dead patient whose organs are being removed for donor purposes

Obesity & Obstructive Sleep Apnea

Reduced lung volumes and an inability to take a deep breath after surgery are a major cause for PPCs. Obesity may further worsen restrictive lung impairment post-operatively. Studies evaluating obesity, do not find it to be a significant risk factor and find no major increase in meaningful PPCs attributable to obesity, even morbid obesity (6.3% for obese versus 7% for no obese patients, respectively)[9]. In a systematic review of 8 studies using multivariate analysis, one study identified obesity as an independent predictor. Overall, obesity does not seem to increase risk for post-operative pulmonary complications [8,9].

Obstructive sleep apnea or OSA increases risk of airway management difficulties in the immediate post-operative period but it's effects on PPCs is not well studied to date. Patients with OSA seem to have a higher likelihood of unplanned ICU transfers, serious complications and increased hospital length of stay than those without OSA[C]. A case-control study on 101 patients undergoing hip or knee-replacement surgery showed that patients with OSA had higher rates of complications (39% vs 18%, p =0.001) including higher rates of intubation, hypercapnia, hypoxemia and longer length of hospital stay than patients without OSA[10].

In a large study of patients undergoing orthopedic and general surgical procedures, patients with OSA were significantly more likely to develop pulmonary complications (i.e. aspiration pneumonia, adult respiratory distress syndrome, intubation/mechanical ventilation). Pulmonary embolism was also more frequent after orthopedic, but not general surgical, procedures. Sleep apnea was deemed an independent risk factor for PPCs[11].

Cigarette Smoking

Current cigarette smokers have an increased risk for PPCs, even in the absence of chronic lung disease. In a prospective cohort study of 410 patients who underwent elective, non-cardiac surgery, smoking was associated with a greater than five-fold increase in the postoperative complication rate (OR = 5.5), after adjustment for type of anesthesia, abnormal chest radiograph, chronic cough, history of pulmonary or cardiac disease, COPD and age. Smokers are also more likely to have a higher rate of unplanned post-operative intensive care admissions compared with nonsmokers[7].

Current smokers who reported reducing cigarette consumption just prior to surgery were more likely to develop a complication compared to those who did not reduce consumption (adjusted OR 6.7)[12].Smoking history of 40 pack years or more increases the risk of pulmonary complications[5].

In an important retrospective study by Nakagawa et al, subjects who were post-operative from pulmonary surgery were divided into groups based on their smoking status. The authors showed that current smokers (smoked within 2 weeks of operation) and recent smokers (abstinence for 2-4 weeks before operation) had the highest rates of PPCs (43.6% and 53.8%, respectively). PPCs were lowest for patients who had an abstinence of 5-8 weeks or longer and it was evident that an abstinence of at least 4 weeks is necessary for patients to reduce the incidence of PPCs[13].

Furthermore, the risk for PPCs for patients who stopped smoking < 2 months compared to those who stopped for >2 months was approximately 4:1 (57% versus14.5%), whereas the risk for PPCs for those who quit smoking for > 6 months was comparable to those who never smoked (11% versus 11.9%)[13].

COPD

Chronic obstructive pulmonary disease is considered a risk factor for PPCs. Patients with severe COPD have higher rates of PPCs particular after cardiac or major abdominal surgery, longer duration of general anesthesia (> 2-4 hours)[14]. Unadjusted relative risk ranges from 2.7 to 6.0[15]. and in a more recent systematic review the impact was less than previously estimated. Using multivariable analysis to adjust for patient-related confounders, the OR for PPCs was 2.36[8].

Asthma

Good evidence suggests that well-controlled asthma does not pose an added risk for PPCs in patients undergoing surgery[8,16].

Pulmonary Hypertension (PH)

Regardless of its etiology, PH (including non-severe PH), increases risk for complications post-operatively particularly in those undergoing emergency procedures, major surgery or those with long operative time[17,18].

Heart failure

Several good quality studies have shown that congestive heart failure is a statistically significant risk factor for PPCs (OR 2.93) even more significant than COPD itself (OR 2.36)[8,9].

Metabolic Factors

Studies have also identified serum blood urea nitrogen (BUN) > 21 mg/dL, serum creating > 1.5 mg/dL and serum albumin levels < 35 g/dL (OR 2.53) as significant risk factors for PPCs. A systematic review found that the magnitude of risk associated with a low serum albumin was similar to the degree of the most important patient-related risk factors and a stronger predictor of risk than an elevated BUN.

Procedure-related risk factors

Surgical site

Surgical site is the most important predictor for PPCs. The incidence of complications is inversely related to the distance of the surgical incision from the diaphragm and the complication rates for upper abdominal and thoracic surgery are amongst the highest (ranging from 10% to 40%)[8]. Aortic surgery (OR 6.90), thoracic surgery (OR 4.24) and abdominal surgery (OR 3.09) carry some of the highest odds of developing PPCs[8].

Incisions in the upper abdomen, across the abdominal muscle effect diaphragmatic motility which in turn leads to reduced vital capacity. Similarly, lateral thoracotomy or incision of the intercostal muscle and introduction of a pleural drain for pleural effusions results in significant post-operative pain subsequently reducing the thoracic compliance in patients with pulmonary disease. Thoracotomy results in thoracic pain causing difficulty in deep breathing and ineffective coughing predisposing these patients to develop atelectasis. There is mucous retention and worsening of gas exchange in patients with pulmonary disease. Patients undergoing cardiac surgery usually require a median sternotomy. These patients are functionally better tolerated than lateral thoracotomy (since it preserves the pleural space) and respiratory function is generally well preserved, except for a transitory reduction in pulmonary volumes.

Duration and type of anesthesia

Based on multivariable studies, prolonged surgery (usually defined as surgery lasting longer than 2.5 to 4 hours), is identified as a risk factor for PPCs (pooled OR 2.26, CI 1.47- 3.47)[8]. This contrasts with risk for postoperative cardiac complications, where duration of surgery is not an independent predictor and is not routinely part of preoperative cardiac risk indices.

As part of a study of risk factors for postoperative pneumonia in 520 patients, it was found that surgeries lasting < 2 hours in duration had an 8% incidence of PPCs, whereas surgeries lasting > 4 hours had an almost 40% incidence of PPCs[7]. Anesthesia time of greater than 3.5 to 4 hours significantly increases risk for PPCs, and it is recommended to attempt less ambitious procedures with a shorter anesthesia time, when possible, and in high risk patients, in order to reduce risk for PPCs.

It appears that general anesthesia (GA) leads to a higher risk for clinically relevant PPCs than epidural or spinal anesthesia, although large scale studies are needed to confirm this. In a study on 2, 644 patients with severe COPD matched with controls, rates of pneumonia (3.3% vs 2.3%, p = 0.0384), prolonged mechanical ventilation (2.1% vs 0.9%, p = 0.0008) and unplanned postoperative intubations (2.6% vs 1.8%, p = 0.0487) were all significantly higher [19].

Similarly, a separate review of matched subjects from large databases (n = 328, 540) showed that when compared with GA, regional anesthesia (spinal, epidural or other) was associated with far fewer pulmonary complications (OR 0.76, CI 0.69-0.84) although there was no major difference in mortality or cardiovascular events[20]. Regional nerve block is preferred and should be considered when possible, for high risk patients.

Type of neuromuscular blockade

Residual neuromuscular blockade is associated with diaphragmatic dysfunction, impaired mucociliary clearance and ultimately increase risk for PPCs. Pancuronium is a long-acting neuromuscular blocker and is known to have a higher incidence of postoperative residual neuromuscular blockade than other agents and hence associated with a significantly higher risk for PPCs [21,22].

SECTION II: Pre-Operative Assessment

Clinical History & Physical Examination

A complete history and physical examination are essential for detecting, and potentially modifying, significant risk factors (as detailed above). Symptoms such as unexplained cough, dyspnea, exercise intolerance suggest chronic lung or heart disease and history & abnormal lung examination findings are crucial in identifying patients at risk for PPCs[23]. It is unclear whether presence of OSA affects post-operative outcomes, however it is considered reasonable to enquire about any symptoms suggestive of sleep apnea as part of the preoperative evaluation.

Potential pulmonary preoperative testing includes:

(1) Pulmonary function testing
(2) Arterial blood gas analysis
(3) Chest radiographs
(4) Exercise testing

Preoperative Pulmonary Function Testing (PFTs)

The goals of performing preoperative testing are generally two fold:

- Identification of patients in whom the risks of proposed surgery are not justified by the benefit
- Identification of patients who are at higher risk and in whom an aggressive perioperative approach is warranted

Studies show that patients undergoing thoracic surgery (coronary artery bypass grafting (CABG) or lung resection surgery) **consistently benefit** from performing pulmonary function testing prior to surgery[24]. For those undergoing extra-thoracic surgery, however, there appears to be little benefit in performing routine preoperative testing and it is recommended for only a select set of cases. Studies show that while,

- Spirometry may help confirm a clinical suspicion of chronic obstructive lung disease, spirometric measurements do not translate into effective risk prediction for individual patients[25,26],
- Spirometry does not appear to be superior to history & physical examination findings [23,25] nor to other factors such as length of surgery, ASA class and the type of procedure (all of which were significant predictors of PPCs)[14,27], and
- Spirometry data studies are unable to provide a prohibitive threshold below which the risk for surgery would be unacceptable.

Recommendation: Spirometry does not appear to add any additional predictive value to information available from preoperative history & clinical examination and is not routinely recommended for patients undergoing extra thoracic surgery[1].

A general approach to performing preoperative PFTs then includes;

- Performing PFTs in patients with COPD or asthma, in whom it is difficult to ascertain from clinical examination whether they are at their baseline or if more can be done to optimize their lung function preoperatively,
- Performing PFTs in patients with unexplained dyspnea in whom undiagnosed cardiac disease is a possibility. This may change preoperative management.
- PFTs **should not** be used as a primary factor to deny surgery & **should not be ordered routinely** prior to high-risk extra thoracic surgery.

Arterial blood gas measurements (assessment of hypoxemia and/or hypercapnia)

It is shown that patients undergoing abdominal surgery who have moderate-severe airway obstruction and hypoxemia (PaO <9.33 kPa) are more likely to have PPCs than those with normal patterns (OR 6.42) . An important study by Canet et al. on a cohort of 2,464 surgical patients found that preoperative oxygen saturation (SpO) measured in a supine position while breathing room air is the strongest patient-related risk factor for development of PPCs (SpO2 ≤ 90% on room air; OR 10.7)[5].

Similarly, for hypercapnia, patients at risk may be identified based on established clinical factors such as advanced COPD or neuromuscular disease, rather than routine ABGs. Small studies have suggested that PaCO > 45 mmHg, usually in patients with underlying severe COPD may increase risk for PPCs although this risk is not prohibitive and may highlight the need for aggressive preparation and/or reevaluation for a need for the surgery[29].

Recommendation: Current data does not support the use of routine preoperative arterial blood gas measurements to stratify patients for risk of PPCs.

Chest Radiography

Evidence from large population-based studies suggests that performing routine preoperative chest radiographs does not alter or predict risk for developing PPCs[59]. In fact, very early on, in countries such as Canada, it was estimated that routine preoperative chest radiographs revealed new information of sufficient importance as to modify management in only 0.1% of cases and that for optimizing health care costs, performing preoperative chest radiographs was not recommended when a reliable history and physical examination were available[31]. Similarly, in a study on 905 patients screened for the presence of clinical risk factors that increase likelihood of having an abnormal x-ray (i.e. age > 60 years and clinical findings consistent with pulmonary or cardiac disease), it was found that when patients had no such clinical risk factors, only 0.3% patients actually had an abnormal chest x-ray. Whereas when patients had these identifiable clinical risk factors, 22% patients had abnormal chest x-rays. This study highlighted that a reliable clinical findings almost always maximize chances of predicting PPCs and additional imaging may not necessarily add more[5] .

Recommendation: Current data does not support routine preoperative chest radiography in most patients. It is considered reasonable to perform chest x-rays in patients who have known cardiopulmonary disease or those who are > 50 years of age and undergoing high risk surgical procedures such as upper abdominal, aortic, esophageal or thoracic surgery.

Preoperative Evaluation for Lung Resection Surgery

Given poor prognosis for patients with lung cancer that is not treated surgically, every effort should be made to identify those patients who will tolerate resection. Operability depends on several factors including tumor type, extent and overall cardiopulmonary reserve of the patient. With a high prevalence of concomitant COPD in patients with lung cancer, all patients are recommended to undergo a screening spirometry and diffusion capacity for carbon monoxide (DLCO) prior to lung resection.

DLCO measurement is considered complementary to spirometry, particularly if there is evidence of diffuse parenchymal disease on imaging or dyspnea out-of-proportion to the measured $FEV_{1.}$ DLCO has highest correlation with post-operative deaths than any other factor and a DLCO < 80% predicted correlates with at least 2-3 times increased risk for pulmonary complications whereas a DLCO <40% predicted correlates with increased mortality.

Preoperative values of forced expiratory volume in one second (FEV_1) >2 L (or >80% predicted) and DLCO >80% predicted suggest that the patient should be able to tolerate surgery including pneumonectomy without further evaluation & correlates with < 5% mortality post-resection[55].

For patients with preoperative FEV_1 < 2 L (or < 80% predicted) or DLCO < 80% predicted, the predicted postoperative (PPO) FEV_1 and DLCO should be calculated, based upon the preoperative values and the fractional functional contribution of the lung to be resected (using anatomical or perfusion methods) (see equations and examples below) (see Figure).

Equations/Examples:

Perfusion method (using VQ scan) (preferred for pneumonectomy)

1. PPO FEV_1 postpneumonectomy = preoperative FEV_1 x (1 - fraction of total perfusion for the resected lung)
2. PPO DLCO postpneumonectomy = preoperative DLCO x (1 - fraction of total perfusion for the resected lung)

Anatomical Method (preferred for lobectomy)

3. PPO FEV_1 post lobectomy = preoperative FEV_1 x $\frac{\text{(1- number of functional lung segments to be removed)}}{\text{total number of functional lung segments}}$

4. PPO DLCO post lobectomy = preoperative DLCO x $\frac{\text{(1- number of functional lung segments to be removed)}}{\text{total number of functional lung segments}}$

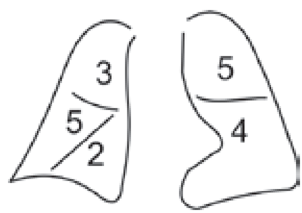
Example:

RUL lobectomy planned, preoperative (=> $_1$ is 70% of predicted

Total lung segments are 19 (see diagram)

RUL lobectomy will entail losing 3 segments

PPO (=> $_1$= 70% x (1 – 3/19) = 67.4 %



Patients with both PPO FEV_1 and PPO DLCO >60% predicted are generally considered low risk and acceptable for surgical resection.

For patients with either PPO FEV_1 or PPO DLCO <60% predicted, but both >30% predicted, a low technology exercise test (i.e. a stair climb test) should be performed. If the patient fails to meet cutoffs for the stair climb test or if either the PPO FEV_1 or PPO DLCO is <30%, a formal cardiopulmonary exercise test (CPET) is indicated with measurement of maximal oxygen consumption (VO_2 max).

Cardiopulmonary exercise testing (CPET) is a sophisticated physiological test that measures maximal oxygen consumption (VO max) and determines anaerobic threshold for individual patients. By measurement of both respiratory and cardiovascular parameters, the test helps to delineate between a predominantly cardiac limitation to maximal aerobic exercise, pulmonary or both. It is useful when the results of PPO FEV_1, PPO DLCO do not clearly define the patient's risk as either high or low. During CPET testing, patients who can achieve a VO max >20 mL/kg per minute are likely to have an acceptable rate of postoperative complications, whereas those with a value <10 mL/kg per min (or less than 35% predicted) are probably best managed by nonsurgical modalities (see work up algorithm).

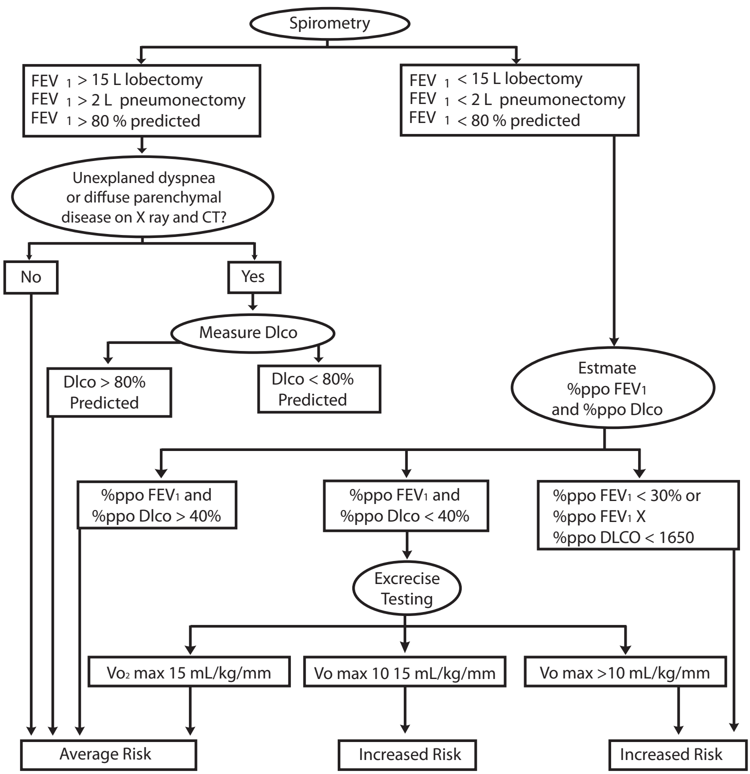


Figure. Recommended Algorithm for Preoperative Evaluation for Lung Resection Sur

Recommendations: All patients with lung cancer shoulder undergo pulmonary function testing to determine candidacy for operability. FEV_1 and DLCO measurements > 80% predicted generally indicate ability to tolerate extensive surgery including pneumonectomy and these patients do not need further evaluation.

Patients with FEV_1 and/or DLCO < 80% should undergo estimation of their postoperative FEV_1 or DLCO. PPO FEV_1 or PPO DLCO < 40% generally indicates patients at high risk for PPCs and mortality. Patients with PPO FEV_1 or PPO DLCO > 40% but < 80% may benefit from undergoing additional testing such as stair climb or cardiopulmonary exercise testing (CPET) to further determine their risk for post-operative complications.

Validated Preoperative Pulmonary Risk Clinical Scores

Risk prediction tools can be used to estimate risk for PPCs. These tools both help identify patients at high risk who then benefit from intensive monitoring post operatively as well as identification of patients who are most likely to benefit from risk factor reduction. All scores provide a numerical risk calculation rather than a subjective/qualitative risk assessment. The following clinical scores are currently available for clinical use:

- ARISCAT (Canet)
- Arozullah respiratory failure index
- Gupta Score

The ARISCAT (Canet) scoring system was developed by group investigators in Spain. Of 2, 464 patients studied reported incidence of at least one PPCs was 5% and regression analysis identified seven independent risk factors that increase risk for PPCs. Namely, **low preoperative oxygen saturation, acute respiratory infection in the last month, upper abdominal or intrathoracic surgery, surgical duration of at least 2 hours, preoperative anemia, age and emergency surgery**. The area under the receiver operating characteristic curve (AUROC) was high, 90% (95% CI, 85-94%) for the development subsample and 88% (95% CI, 84-93%) for the validation subsample. The subsequent risk for PPCs is classified as low-, intermediate- and high risk (i.e. 1.6%, 13.3% and 42.4%) (see table)[5]. This score is simple and composed of easily available clinical parameters, making is relevant for use at the bedside. It has also been subsequently validated in a large cohort of 5099 patients across Europe [58].

Table. ARISCAT (Canet) Risk Index (Validated)

Predictor	Multivariate Analysis OR	Risk Score
Age 51-80 years	1.4	3
Age > 80 years	5.1	16
Preoperative SpO2 91-95%	2.2	8
Preoperative SpO2 < 90%	10.7	24
Resp. Infection < 1 month	5.5	17
Preoperative Hb < 10 mg/dL	3.0	11
Upper abdominal incision	4.4	15
Intrathoracic incision	11.4	24
Surgery 2-3 hours	4.9	16
Surgery > 3 hours	9.7	23
Emergency procedure	2.2	8

Risk Category	PPC rate
Low risk < 26 points	1.6%
Intermediate risk 26-44 points	13.3%
High risk > 45 points	42.1%

Another scoring system, the Arozullah respiratory failure index, was developed based on retrospective data from a cohort of 81, 719 patients from 44 Veterans Affairs Medical Centers. It predicts risk for post-operative respiratory failure (defined as mechanical ventilation > 48 hours) after surgery or reintubation and mechanical ventilation after postoperative extubation. Simplified logistic regression models revealed that **type of surgery (abdominal aortic aneurysm, thoracic, neurosurgical, upper abdominal or vascular, neck), emergent surgery, albumin < 3.0 g/dL and blood urea nitrogen > 30 mg/dL, functional status, COPD and age** – were independent predictors for PPCs. This risk index is a validated model for identifying patients at risk for developing post-operative respiratory failure, as defined above [35]. The Gupta Score was developed from multicenter, prospective data (American College of Surgeons National Surgical Quality Improvement Program (NSQIP)), in which 211,410 patients were part of the training set (2007) and 257,385 patients were part of the validation set (2008). Five preoperative predictors of post-operative respiratory failure were identified: **type of surgery,**

emergency case, dependent functional status, preoperative sepsis, and higher American Society of Anesthesiologists (ASA) class. The area under the receiver operative curve (AUROC) was high for both the training and validation sets (i.e. 0.894 and 0.897, respectively) – indicative of an excellent predictive performance. The risk model was used to develop an interactive risk calculator which is readily available online (http://www.surgicalriskcalculator.com/postoperative-pneumonia-risk-calculator).Gupta score predictors risk for postoperative respiratory failure (defined as requiring mechanical ventilation>48 hours after surgery or unplanned intubation within 30 days of surgery) and is expected to aid in surgical decision making[5A].

Section III: Risk Modification

Patients identified to be at a high risk for PPCs benefit from risk reduction strategies to improve outcomes. General followed by disease-specific strategies are highlighted here. Broadly these strategies can be classified as follows:

General Strategies

Preoperative Strategies

- Smoking cessation
- Treatment of respiratory tract infections
- Preoperative exercise and pulmonary rehabilitation

Intraoperative Strategies

- Anesthesia
- Type of surgery
- Duration of surgery
- Lung Protective Ventilation

Post-operative Strategies

- Lung expansion
- Pain control
- Prevention of venous thromboembolism
- Mobilization

Disease-Specific Recommendations

Pre-Operative Measures

Smoking Cessation

Cigarette smoking is an independent risk factor for PPCs[37,39]. The precise preoperative period of abstinence required for favorable postoperative outcome is not known but several studies highlight the beneficial effects of cessation even as early as 2-8 weeks prior to surgery. The longer the duration of abstinence, the better the outcomes are expected to be in terms of PPCs[13,40,41]. Smoking cessation for even a few weeks is associated with a reduction in secretions, improved mucociliary clearance, improvement in oxygenation (reduction of carboxyhemoglobin)[8].

Nakagawa et al. in an important retrospective analysis described that patients who smoked 2-4 weeks prior to surgery had a much higher incidence of PPCs (53.8%) versus never smokers (23.9%). The odds of developing PPCs for patients who smoked < 2 weeks of surgery, 2-4 weeks before surgery and > 4 weeks prior to surgery were 2.09 (95% confidence interval (CI), 0.83 to 5.25), 2.44 (95% CI, 0.67 to 8.89), and 1.03 (95% CI, 0.47 to 2.26), respectively[13].

In another metanalysis of 25 studies, the risk of respiratory complications was higher in those who smoked < 2 weeks or 2-4 weeks prior to surgery (Relative Risk [RR] 1.20; 95% CI 0.96 to 1.50 and RR 1.14 (CI 0.90 to 1.45), respectively. Smokers who quit > 4 weeks and > 8 weeks before surgery had lower risks of respiratory complications than current smokers (RR 0.77; 95% CI 0.61 to 0.96 and RR 0.53; 95% CI 0.37 to 0.76, respectively[89].

A systematic review including 6 randomized trials and 15 observational studies showed that > 4 weeks of smoking abstinence had better outcome when compared to shorter duration of cessation (p=0.04)[41]. Based on this, an ideal period of abstinence prior to surgery is 8 weeks.

The preoperative period can serve as an effective for a successful smoking cessation attempt[43]. Patient should be given both behavioral and pharmacological support (i.e. nicotine replacement therapy, varenicline, bupropion) for smoking cessation as intensive interventions are likely to have a positive impact on long-term postoperative smoking cessation[44].

Recommendation: Preoperative smoking cessation is associated with favorable postoperative outcomes. Where possible, smoking cessation should be instituted at least 8 weeks or more prior to elective surgery. Patients should be offered both behavioral & pharmacological support for smoking cessation as the preoperative period can serve as an opportunity for smoking cessation

Treatment of upper respiratory tract infections

Patients with signs and symptoms of a respiratory tract infection should be treated prior to undergoing elective surgery. Upper respiratory tract infections (URTIs) can lead to increased upper airway reactivity resulting in an increased risk of postoperative complications[34,45]. In some cases, surgery may be delayed if the risk of PPCs are considered to outweigh the benefits of surgery[46].

Recommendation: Patients with signs and symptoms of an upper respiratory tract infection should be treated before proceeding for elective surgery

Preoperative exercise and pulmonary rehabilitation

Postoperative lung expansion maneuvers help in reducing PPCs and there is evidence that preoperative breathing exercises & rehabilitation have a positive impact. Inspiratory muscle training (IMT) which includes incentive spirometry, forced expiratory and active breathing techniques are shown to reduce PPCs in patients undergoing abdominal, thoracic and cardiac surgeries[47,49]. Preoperative respiratory muscle training showed to reduce the incidence of post-operative atelectasis and mean increase in inspiratory pressure of 10%[48].

A meta-analysis of 8 randomized control trials on 856 patients showed those who received preoperative physical therapy had reduction is post-operative atelectasis (RR 0.52; 95% CI 0.32 to 0.87, p = 0.01) and pneumonia (RR 0.45; 95% CI 0.24 to 0.83, p = 0.01).However, groups did not differ with respect to days of mechanical ventilation and all-cause mortality[49].

Another systematic review including 12 trials with 695 patients showed similar results. Five of these trials included patients undergoing cardiac surgery and seven of these trials had patients undergoing abdominal surgery. There was a reduction of postoperative atelectasis and pneumonia in those who undergone preoperative IMT as compared with the non-exercise intervention (RR 0.53, 95% CI0.34 to 0.82 and RR 0.45, 95% CI 0.26 to 0.77, respectively). However, its effect on all-cause mortality was uncertain (RR 0.40, 95% CI 0.04 to 4.23)[50].

Starting and emphasizing breathing exercises and lung expansion maneuvers in the preoperative period rather than the post-operative is likely to be more practical and effective, as post-operative pain and sedative effects of analgesics may limit patient's ability to understand the significance of these measures in immediate postoperative period [51,52].

Recommendation: Pulmonary rehabilitation and breathing exercises have a positive impact and reduce post-operative atelectasis, PPCs. Whenever possible, these exercises should be emphasized in the preoperative period

Intra-Operative Strategies

Anesthesia

General anesthesia (GA) is an independent risk factor for PPCs because it alters respiratory mechanics, impairs diaphragmatic action and reduces lung volumes and capacity. This predisposes patients to developing atelectasis, VQ mismatch and hypoxemia[53].

A Cochrane review revealed that patients undergoing neuraxial blockade in comparison to GA, had reduced rates of pneumonia (RR 0.45, 95% CI 0.26 to 0.79) and 30-day mortality (RR 0.71, 95% CI 0.53 to 0.94)[54]. This is also shown in a study that compared 2,644 patients undergoing GA vs regional anesthesia, who were matched for comorbidities and type of surgery. GA was associated with a higher incidence of pneumonia (3.3% versus 2.3%, p = 0.0384), prolonged mechanical ventilation (2.1% versus 0.9%, p = 0.0008) and unplanned postoperative intubation (2.6% vs 1.8%, p = 0.0487) [19].

When using neuromuscular blocking agents (NMBAs) during GA, use of short or intermediate-acting agents(i.e. cisatracurium, mivacurium, rocuronium, vecuronium) is preferred over long-acting agents (i.e. pancuronium). Complete reversal of neuromuscular blockade at the end of surgery is imperative as residual paralysis of pharyngeal and other muscles can increase risk for aspiration, hypoventilation, hypoxemia, delayed extubation, prolonged recovery and PPCs[55-57].

Recommendation: For a surgery, if both general and neuraxial (spinal/epidural) anesthesia are available & possible, the latter is preferred, especially for high-risk patients

When using neuromuscular blockade during general anesthesia, short or intermediate-acting agents are preferred over long acting ones. Complete reversal of neuromuscular blockade at the end of surgery is imperative to prevent risk for aspiration and PPCs etc.

Type and duration of surgery

Open thoracotomy, head &neck, upper abdominal and open aortic surgeries carry the highest risk for PPCs. Emergency surgery moderately increases the risk of PPCs[8]and surgical procedures >2 hours have a higher likelihood of PPCs (> 2 hours; OR 4.9 (CI2.4–10.1) and > 3 hours; OR 9.7 (CI 4.7–19.9)[5]. Although the type of surgery is a non-modifiable risk factor, other modifiable risks should be addressed and optimized for all patients. Where surgically appropriate, laparoscopic or video-assisted surgeries should be preferred over open surgeries. High-risk surgical procedures should be performed by the experienced surgeons so that the duration of surgery is limited [1].

Recommendation: When surgically appropriate, laparoscopic or video-assisted surgeries are be preferred over open surgeries. High-risk surgical procedures should be performed by the experienced surgeons so duration of surgery can be limited as much as possible

Intraoperative ventilation

Lung protective ventilatory (LPV) strategy has proven benefits in patients with ARDS. It is also associated with good outcomes in patients undergoing abdominal surgery. LPV strategy includes delivery of tidal volumes of 6-8mL/kg (ideal body weight), positive end-expiratory pressure or PEEP (variable) and use of recruitment maneuvers. Effect of lung-protective mechanical ventilation in other surgical settings is not known.

Futier et al. divided patients undergoing abdominal surgery who were intermediate to high-risk for pulmonary complications, to receive intraoperative non-protective mechanical ventilation (tidal volume of 10-12 mL/kg predicted body weight, no PEEP and no recruitment maneuvers) or intraoperative protective mechanical ventilation (tidal volume 6-8 mL/kg of predicted body weight, PEEP 6-8 cm of water, and recruitment maneuvers repeated every 30 minutes after tracheal intubation). The primary outcome of major pulmonary and extrapulmonary complications occurring within 7 days after surgery occurred in 21 of 200 patients (10.5%) in the lung-protective ventilation arm and 55 of 200 (27.5%) in the non-protective ventilation arm (RR 0.40; 95% CI 0.24 to 0.68; p =0.001)[58]. Similar effects have also been shown in other studies [59,60]. Intraoperative lung protective ventilation improves outcomes.

Judicious use of fluids intra- and postoperatively avoids risk for pulmonary edema and lung injury[61]. A positive fluid balance can cause delays in extubation and prolong ICU stay.

Recommendation: Use of lung protective ventilation (tidal volume 6-8 mL/kg of ideal body weight) intraoperatively reduces risk for PPCs. In addition, judicious use of fluids both intra- and postoperatively avoids risk for pulmonary edema, lung injury, delayed extubation or prolonged ICU stay

Post-Operative Strategies

Lung expansion

A variety of lung expansion strategies has been used by physiotherapist to reduce PPCs including incentive spirometry, positive expiratory pressure (PEEP), inspiratory resistance combined with PEP, deep breathing exercises, assisted coughing, vibration, coughing and noninvasive ventilation (CPAP/BiPAP). There is no evidence of the benefit of one technique over the other or the use of mechanical devices to be superior to deep breathing exercises[62-64]. These measures especially should be taken in patients undergoing surgeries with higher rates of PPCs i.e. thoracic, abdominal and aortic surgeries[62-65].

ICOUGH is an acronym for a multidisciplinary team strategy to reduce PPCs. It includes incentive spirometry, coughing, and deep breathing, oral care (brushing teeth and using mouthwash twice daily), understanding (patient and family education), getting out of bed at least 3 times daily, and head-of-bed elevation. It showed to reduce the incidence of postoperative pneumonia from 2.6% to 1.6% and unplanned intubations from 2.0% to 1.2 %

In patients who are unable to perform effort dependent lung expansion maneuvers for various reasons, the use of noninvasive ventilation (BiPAP /CPAP) can be helpful. A meta-analysis of 9 randomized trials of patients undergone abdominal surgery, showed a significant reduction of PPCs in patients received CPAP as compared to standard care[67]. A study of 500 patients who undergone elective cardiac surgery were randomly assigned to nasal CPAP of 10cm H_2O for 6hours (study) and 10 minutes of intermittent nasal CPAP of 10cm H_2O every 4hours (control).The study group showed a reduction in pneumonia, hypoxemia, re-intubation, and ICU readmission rates[68].

Recommendation: Use of lung expansion maneuvers in the postoperative period is associated with a reduction of PPCs. No one technique is shown to be superior over another (nor are mechanical devices superior to deep breathing exercises)

Mobilization

Post-operatively, early mobility is very important. It helps in lung expansion and reduction in atelectasis. A trial involving 72 patients who underwent high-risk abdominal surgery, the risk of PPCs increased 3 times (95% CI 1.2 to 8.0) for each postoperative day they did not mobilize out of bed[69]. A retrospective analysis of 118 patients who underwent VATS esophagectomy showed, the incidence of postoperative atelectasis reduced with early mobilization[70].

Recommendation: Post-operatively, early mobilization is associated with a reduction of PPCs

Pain control

Optimal pain control is crucial for patient's ability to take deep breaths and participate in postoperative physiotherapy including early ambulation. Postoperative pain leads to splinting of the diaphragm and decreased movement of the chest with resultant atelectasis, hypoxemia, and pneumonia.

Depending on the type of surgery adequate pain control should be achieved. For mild pain, acetaminophen or non-steroidal anti-inflammatory agents (NSAIDs) can be used. Opioid analgesics should be used cautiously, especially in patients with COPD and OSA who are at risk for respiratory depression with opioid use.

Epidural analgesia is shown to improve outcomes after major or high-risk surgeries. In a systematic review of 125 randomized control trials including adult patients who underwent surgery, epidural analgesia significantly decreased the risk of, deep vein thrombosis, respiratory depression, atelectasis, pneumonia in addition to other extrapulmonary complications[71]. Similarly, in a study of 324 patients with COPD who underwent major abdominal surgery, use of epidural analgesia reduced postoperative pneumonia (16% vs. 11%; $p = 0.08$) and 30-day mortality (9% vs. 5%; $p = 0.03$)[72] . Epidural anesthesia is shown to be superior in terms of pain control, when compared with intravenous patient-controlled opioid analgesia[73], allows the duration of mechanical ventilation to be significantly shortened (by about 48%)[74] and reduces incidence of respiratory failure[75].

Recommendation: Adequately controlled post-surgical pain allows for early mobility and a better adherence to breathing exercises, resulting in a reduction of PPCs.

Epidural analgesia is shown to improve several outcomes (particularly risk for post-operative pneumonia, duration of mechanical ventilation and risk for respiratory failure) and should be considered in high-risk surgeries

Prevention from Venous thromboembolism (VTE)

Strategies to reduce the risk of VTE include early ambulation, mechanical and pharmacological thromboprophylaxis. The choice of thromboprophylaxis should be based on the estimated postoperative risk of VTE and postoperative risk of bleeding.

Recommendations: Post-operative VTE prophylaxis should be administered based on the estimated risk of VTE and bleeding

Optimization of underlying pulmonary disease

Asthma

Asthmatic patients should be assessed for asthma control prior to undergoing surgery. Relevant history includes history of exacerbations, use of systemic corticosteroid therapy, hospitalizations or ER visits, history of mechanical ventilation, prior perioperative exacerbation and frequency of need for reliever medications.

Well-controlled asthma essentially poses no additional risk for PPCs[8]. Warner et al. showed lower rates of perioperative complications in asthmatics but when complications do occur, they tend to be in older asthmatics, patients who have increased use of bronchodilator medications within 30 days of surgery, recent symptomatic exacerbations or a recent visit to a medical facility for treatment of asthma [16].

Regular treatment of asthma including combination inhaled corticosteroid/long acting beta agonist (ICS/LABA) and an as-needed reliever should be continued in the pre- and postoperative period[76].

In case of uncontrolled asthma or history of fixed airflow limitation, every attempt should be made to achieve asthma control by stepping up the treatment and if needed use systemic steroids [76]. In case of urgent procedures, the risk of undergoing surgery with uncontrolled asthma should be weighed against the benefits of undergoing surgery. If the patient is already on inhaled steroids, then he/she should be treated with prednisone 0.5 mg/kg for 5 days prior to surgery. If the patient is on oral steroids chronically, then the dose should be increased for 5 days prior to surgery[77].

Patients at a high risk for hypothalamic-pituitary adrenal (HPA) axis suppression (i.e. those on high dose long-term ICS therapy & those who have received systemic corticosteroid therapy for over 2 weeks in the last 6 months benefit from perioperative stress dose steroid therapy (IV hydrocortisone 100mg every 8 hours)[76]. Preoperative systemic steroids are not associated with delayed wound healing, wound infections, postoperative bronchospasm or adrenocortical insufficiency[78,79].

Airway manipulation during tracheal intubation can lead to bronchospasm which can be life-threatening[80]. This can be prevented by premedicating with inhaled beta-2 agonists[81]. Anesthetic agents with bronchodilatory properties are preferred. For instance, inhaled agents such as sevoflurane and isoflurane have inherent bronchodilatory effects, whereas intravenous ketamine causes bronchodilation and propofol has a protective effect against increased airway resistance during tracheal intubation via vagally mediated relaxation of airway smooth muscles[82].

Intraoperatively, mechanical ventilation should be adjusted to avoid air-trapping and dynamic hyperinflation (i.e. via allowing a prolonged expiratory time or alow minute ventilation) Permissive hypercapnia is acceptable but there should be careful monitoring of arterial blood gases[83].

NSAIDs should be avoided in patients with a history of aspirin-exacerbated respiratory disease.

Recommendation: Well-controlled asthma poses no additional risk for PPCs. Regular treatment including use of ICS/LABA and an as-needed reliever should be continued in the preoperative and postoperative period. Patients with poorly controlled asthma require close attention and optimization prior to surgery. Patients at high risk for HPA axis suppression (from chronic systemic or high dose ICS use) benefit from use of systemic stress-dose corticosteroids during the perioperative period

Chronic Obstructive Pulmonary Disease

COPD is an independent risk factor for postoperative pulmonary complications[8,27]. Severity of COPD itself, as well as comorbidities associated with COPD, (i.e. poor overall health/nutritional status, low body weight, coronary arterial disease and heart failure) add to the risk of PPCs in these patients.

GOLD guidelines recommend that all COPD patients with either symptoms or exercise-limitation should be aggressively medically optimized prior to surgery. In addition, underlying comorbid conditions should also be assessed and optimized prior to elective surgeries[84].

Patients who have received frequent systemic corticosteroids for recurrent exacerbations are at risk of developing postoperative adrenal insufficiency. Use of prednisone >7.5 mg or equivalent for more than 30 days or >20 mg for more than two weeks in last 6months generally qualifies most patents for perioperatives[85] tress dose steroid therapy[86].

Where possible neuraxial anesthesia should be preferred over general anesthesia. Using data from the NSQIP database, Hausman et.al compared patients with COPD who had surgery under general anesthesia, spinal, epidural or peripheral nerve block. Patients who underwent general anesthesia when compared with regional anesthesia had higher incidence of postoperative pneumonia (3.3% versus 2.3%, p = 0.0384, absolute difference 1.0% (95% CI 0.09 - 1.88), prolonged ventilator dependence (2.1% versus 0.9%, p = 0.0008, absolute difference = 1.2% (95% CI 0.51 -1.84) and unplanned postoperative intubation (2.6% versus 1.8%, p = 0.0487, absolute difference = 0.8% (95% CI 0.04 - 1.62)[19].

As previously discussed for asthmatic patients, anesthetic agents with bronchodilatory properties are preferred for induction & maintenance of anesthesia (i.e. isoflurane, ketamine and propofol) in COPD as well[82]. Lung protective ventilation & techniques to avoid dynamic hyperinflation should be utilized (i.e. reduced minute ventilation and greater expiratory time)[83,87,46]. At the end of the surgery, every attempt should be made to achieve complete reversal of neuromuscular blockade prior to extubation. Noninvasive ventilation (NIV) can be used for facilitating weaning from mechanical ventilation. A meta-analysis revealed that use of NIV post extubation reduces reintubation rates (OR 0.24, 95% CI 0.12-0.5),post-operative pneumonia rates(OR 0.27, 95% CI 0.09-0.77),and increases hospital survival post-surgery (OR 4.54 (corrected) 95% CI 1.35-15.31)[88].

Recommendations: COPD patients with symptoms or exercise-limitation should be managed aggressively with medical optimization to achieve as stable a baseline status as possible, prior to surgery

Patients with a history of frequent use of systemic corticosteroids benefit from stress-dose corticosteroid therapy in the perioperative period

Neuraxial anesthesia should be preferred over general anesthesia, whenever possible

Anesthetic agents with bronchodilatory properties should be preferred intraoperatively. In addition, lung protective mechanical ventilation and strategies to avoid dynamic hyperinflation or airtrapping should be utilized.

Non-invasive ventilation can be used to facilitate weaning from mechanical ventilation post-operatively.

Obstructive sleep apnea (OSA)

OSA is an independent risk factor for developing PPCs[89]. OSA has been associated with a difficult-to-manage airway, hypoxemia, hypercapnia, atelectasis, pneumonia, pulmonary edema, pulmonary embolism and reintubation[11,85,89,90]. The decrease in pharyngeal tone with the use of opioids, anesthesia and sedatives worsens sleep apnea.

During preoperative evaluation, the results of past polysomnography should be reviewed with CPAP/BiPAP settings in patients already diagnosed to have obstructive sleep apnea. Patients should bring their own CPAP devices to the hospitalfor use in the pre- &postoperative period[91].

Patients with diagnosed OSA but noncompliant to PAP therapy should additionally be evaluated and managed for unoptimized associated illnesses such as group 3 pulmonary hypertension (PH), resting hypoxemia and hypoventilation syndromes [91].

In patients who are undiagnosed but considered high risk to have OSA, the decision to proceed for surgery should factor in the urgency of the procedure, perceived severity of OSA and associated comorbidities. The risks and benefits of surgery before diagnosis and optimization of OSA along with its comorbidities should be discussed prior to surgery with patients[91].

Patients with OSA are at an increased risk of having a difficult-to-manage airway and hence need adequate precautions[92]. Where appropriate, regional anesthesia should be preferred over general anesthesia. Agents that decrease pharyngeal tone & increase risk of post-operative pulmonary complications, such as benzodiazepines and opioids should be used with caution. Propofol increases risk of respiratory compromise and hypoxemia and it's use in patients with OSA should be matched with careful monitoring & titration of dose to achieve desired effects[92].

After induction of anesthesia, there is an approximately 50% reduction in functional reserve capacity (FRC) of the lung due to atelectasis. Atelectasis reduces lung compliance far more than it alters chest wall compliance [93,94]. In order to reduce atelectasis, lung protective ventilator strategy should be used intraoperatively (i.e. tidal volumes ranging 6 to 8mL/kg of ideal body weight, PEEP > 5cm H_2O and use of lung-recruitment maneuvers where needed. Adjustments in respiratory rate (RR) are used to control end-tidal carbon dioxide/arterial partial pressure of carbon dioxide[93].

Patients should be extubated when fully awake and after complete reversal of neuromuscular blockade. In recovery, the patient should be in a semi-recumbent or a lateral position. There should be careful monitoring of hemodynamics and oxygen saturation. In the case of desaturation, CPAP therapy should be applied[95,96]. Opioid analgesics should be avoided whenever possible, especially in the postoperative setting, in patients with obstructive sleep apnea [95].

Recommendations: Patients with known OSA should bring and use their own BiPAP/CPAP device in the perioperative period

Patients who are known to have OSA but are non-compliant with recommended positive airway pressure (PAP) therapy, should additionally be evaluated & managed for potentially associated systemic comorbidities such as PH, preoperatively

In patients who are undiagnosed but deemed highly likely to have OSA, the decision to proceed with surgery should factor in both the urgency & benefit of the proposed procedure versus the risks of untreated OSA and its associated comorbidities

Regional anesthesia should be preferred over general anesthesia, whenever possible

Intraoperatively, lung protective ventilation should be used, and patients should be extubated when fully awake and after complete reversal of neuromuscular blockade

In the postoperative period, opioid analgesics should be avoided whenever possible

Pulmonary Hypertension (PH)

Perioperative evaluation and management of patients with pulmonary hypertension requires a multidisciplinary team approach comprising of pulmonary & critical care physicians, cardiologists, surgeons & anesthesiologists.

In patients with a poor exercise capacity, i.e. New York Heart Association (NYHA) Class III or IV, right ventricular (RV) dysfunction – a decision to proceed for surgery should be carefully considered [42,97]. NYHA or WHO functional class ≥ 2, 6 minute walk distance (6MWD) covered < 300 m, history of coronary artery disease (CAD), history of pulmonary embolism, history of chronic renal insufficiency, right ventricular hypertrophy (RVH) with severe systolic dysfunction, higher mean pulmonary artery pressures, emergency surgery, intermediate-highrisk surgery, ASA physical status > 2, duration of anaesthesia > 3 hours, use of vasopressors intraoperatively, are some of the factors shown to be associated with increased morbidity and mortality[17,18,98-100].

Medical therapy should be optimized in preparation for surgery. Initiation & optimization of pulmonary arterial hypertension (PAH)-specific therapies for WHO group 1 pulmonary hypertension, diuretics and appropriate heart failure therapies for patients with WHO group 2 pulmonary hypertension, optimization of oxygen, bronchodilators, inhaled or systemic steroids for obstructive airway disease patients and use of positive airway pressure (PAP) therapy in patients with obstructive sleep apnea, should be recommended[101,102].

The anesthesiologist should preferably be a specialist in cardiovascular or critical care anesthesia with experience in managing complex intraoperative hemodynamics [42,103]. Intraoperatively, factors that can increase in pulmonary artery pressure or pulmonary vascular resistance (PVR) such as inadequate pain control, hypoxemia, hypercapnia, acidosis, hypothermia, excessive PEEP or increased airway pressures – should be avoided [42,97,103].

An invasive arterial line should be used for monitoring hemodynamics as it helps in early recognition in case of instability [97,102] and also with frequent arterial sampling for the measurement of PaO , PaCO and pH. Intraoperative central venous pressure (CVP) measurements help maintaining preload and detection of new-onset tricuspid insufficiency[97,102,105].

There is no robust data to support the use of pulmonary artery catheter (PACs) intraoperatively in non-cardiac surgeries as no studies have shown a definitive benefit in clinical outcomes from their use [104]. However in high-risk surgical patients, PAC monitoring can be of use to provide accurate assessment of pulmonary artery pressure, cardiac output, pulmonary capillary wedge pressures (PCWP) to determine a need of vasopressors or fluids and in the acute management of a perioperative PH crisis [97,102]. The risks and benefits of inserting a PA catheter should be assessed individually in each patient. Alternatively or as an adjunct to PAC, a transesophageal echo (TEE) can be inserted to help determine pulmonary arterial pressures, RV size and function particularly in surgeries with rapid blood loss[97,102,105].

There are no comparative studies for the use general versus regional anesthesia in patients with PH. Depending on the type of surgery and underlying comorbidities, either type of anaesthesia can be opted for. In the case of neuraxial anesthesia, epidural is preferred over spinal due to an ability to bolus slowly using epidurals and with a more gradual titration with a controlled onset of effect [101,102,106]. Regional techniques can be used postoperatively for adequate pain control.

In the case of general anesthesia, intubation should be performed by an experienced anesthesiologist. The patient should be preoxygenated with 100% oxygen and intubation should be performed smoothly with adequate depth of anesthesia to avoid any sympathetic stimulation that could have deleterious effects on right ventricular after load [102]. Etomidate and opiates are preferred induction agents as they have minimal effects on myocardial contractility and PVR[97,102,107]. In patients with PH, single lung ventilation should be avoided as it can result in a reduction of blood flow in the non-ventilated lung leading to an exacerbation of PH & even RV failure[97].

Systemic hypotension increases risk of RV ischemia. Vasopressors can be used to avoid hypotension. Norepinephrine and vasopressin are preferred vasopressors as they reduce the pulmonary-systemic vascular resistance ratio and marginally improve cardiac output[97,102,108,109]. Inotropes such as milrinone and dobutamine can be used with vasopressors to increase cardiac output [110]. A heart rate between 60 to 90 beats per minute is considered physiological and bradycardias or tachycardias can both can be problematic in the setting of PH[111]. Antiarrhythmics can be used to maintain normal sinus rhythm and prevent arrhythmias that can reduce cardiac output and cause hypotension. Atrial fibrillation for instance, should be managed pharmacologically or via synchronized cardioversion [112].

Intraoperatively, lung protective ventilator strategy should be used. Over inflation with lung volumes above FRC or high PEEP can result in occlusion of the small intra-alveolar vessels and increase PVR. It is ideal to keep tidal volumes between 6 to 8 mL per kg of ideal body weight and use higher FiO2 rather than high PEEP to maintain oxygenation. Ideal PEEP may range between 5 to 10 cm H O.To avoid acidosis or hypercapnia (both of which can worsen PVR), pH should be targeted to > 7.40 while allowing permissive hypocapnia i.e. $PaCO_2$ 30 – 35mmHg [97,101,112,113].

A patient with pulmonary hypertension should be monitored postoperatively in the intensive care unit (ICU). Pain can increase PVR because of sympathetic stimulation and should be adequately controlled. Regional blocks and epidural analgesia can prove beneficial in such cases. Opioids can lead to hypoventilation with resultant hypoxia and hypercapnia and so should be avoided. Non- steroidal anti-inflammatory agents may be considered for effective pain management [97,101,102].

Hypoxia, acidosis and hypothermia should be avoided. Postoperative infections should be treated aggressively as these are poorly tolerated by patients with PH and RV preload should be optimized by avoiding hypo- or hypervolemia[101].

Mean arterial pressures (MAP) should ideally be kept greater than 60mmHg and vasopressors can be used to achieve these targets. Atrial tachyarrhythmias have detrimental effects on RV function and can precipitate RV failure[114]. Beta-blockers and calcium-channel blockers should be used cautiously. Agents such as digoxin and amiodarone can be considered to control atrial arrythmias [101,102]. PAH-specific therapies can be started in the postoperative period.

Recommendation: Perioperative evaluation and management of patients with pulmonary hypertension requires a multidisciplinary team approach that includes a pulmonary & critical care physician, cardiologist, surgeon and anesthesiologist

In patients with underlying pulmonary hypertension medical management should be optimized based on WHO pulmonary hypertension group-specific therapies, prior to proceeding with surgery

Invasive hemodynamic monitoring is needed for intraoperative monitoring and management

Physiological factors that increase pulmonary artery pressure or pulmonary vascular resistance should be avoided intraoperatively and patients with PH should be monitored in the ICU, post operatively

Pain should be adequately controlled postoperatively, as it can increase pulmonary vascular resistance and precipitate RV failure

Restrictive lung diseases

Literature is sparse on the perioperative management of patients with restrictive lung disease. These patients should be optimized for any associated comorbid conditions, i.e. hypoxemia associated pulmonary hypertension etc. and general strategies to prevent PPCs, as mentioned above, should be considered.

Patients with idiopathic pulmonary fibrosis (IPF) in particular should not undergo surgery at the time of an active exacerbation as this has been shown in studies to be an individual risk factor for increased 30-day mortality[115,116]. Considering a high risk for PPCs and mortality, the benefits of the proposed surgery should be weighed carefully against the risks in patients with restrictive lung impairment.

Recommendation: Considering a high risk for PPCs and mortality, the benefits of the proposed surgery should be weighed carefully against the risks in patients with restrictive lung impairment.

Table. Strategies to reduce post-operative pulmonary complications

Preoperative strategies	• Smoking cessation for at least 8 weeks prior to surgery • Treatment of upper respiratory tract infections • Start breathing exercises and pulmonary rehabilitation preoperatively • Optimization of medical management of underlying pulmonary diseases as per disease specific guidelines.
Intraoperative strategies	• Perform surgeries under neuraxial anesthesia where possible instead of general anesthesia. • Prefer laparoscopic surgeries over open surgeries when possible • Avoidance of long acting neuromuscular blocking agents • Intraoperative use lung protective ventilator strategy • Extubation of patient after complete reversal of effects of neuromuscular blocking agent.
Postoperative strategies	• Adequate pain control with use of epidural analgesia in high risk patients • Early mobilization • Chest physiotherapy along with breathing exercises and use of CPAP where necessary • Thromboprophylaxis for VTE prevention

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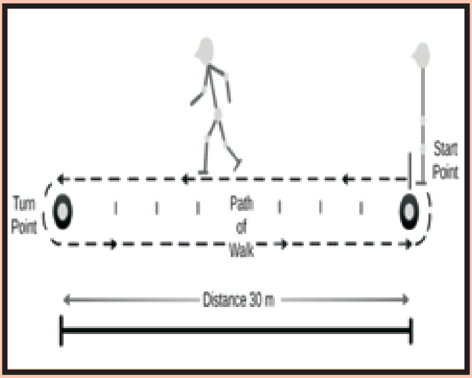
STRIVING FOR PULMONARY CARE



Characteristic	Healthy	Affected	*P*-Value
Age (years)	5.1 ± 4.5	10.8 ± 2.3	<.001
Weight (kg)	22.9 ± 11.2	11.9 ± 8.2	.01
BCS	5.6 ± 0.8	6 ± 0.5	.13
Leg length (cm)	26.5±7.1	18.3 ± 6.2	.01
Distance walked (m)	522.7 ± 52.4	384.8 ± 4.0	<.001
Pre-SpO_2 (%)	98 ± 1	92 ± 3	<.001
Post-SpO_2 (%)	97 ± 1.5	91 ± 3	<.001
Pre-HR (bpm)	112 ± 25	129 ± 28	.13
Post-HR (bpm)	112 ± 20	132 ± 23	.02

6MWT, 6-minute walk test; BCS, body condition score; HR, heart rate; SpO_2, oxygen saturation as assessed by pulse oximetry.

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