Preoperative Assessment of Pulmonary Risk*

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Study objectives: **A summary of current modalities for and the utility of preoperative assessment of pulmonary risk.**
Design: **Review of recent literature published in the English language.**
Setting: **Not applicable.**
Patients or participants: **Patients who undergo elective cardiothoracic or abdominal operations.**
Interventions: **Not applicable.**
Measurements and results: **Postoperative pulmonary complications occur after 25 to 50% of major surgical procedures. The accuracy of the preoperative assessment of the risk of such complications is only fair. The routine assessment for all preoperative patients includes age, general physiologic status, and the nature of the planned operation. Specific tests such as measurement of spirometric values and diffusing capacity are indicated routinely only for patients who are candidates for major lung resection or esophagectomy.**
Conclusions: **Pulmonary complications are an important form of postoperative morbidity after major cardiothoracic and abdominal operations. The appropriate preoperative assessment of the risk of such complications is well defined for lung resection and esophagectomy operations, but it requires refinement for general surgical and cardiovascular operations.**
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Pulmonary complications are the most common form of postoperative morbidity experienced by patients who undergo general surgical abdominal procedures and thoracotomy, and frequently occur after cardiac surgical operations. The cost of postoperative pulmonary complications was well recognized at the beginning of the 20th century, at which time a number of clinical reviews identified the mortality rate associated with the development of postoperative pneumonia among $> 40{,}000$ patients to be in excess of 40%.[1–8] In addition to pneumonia, postoperative pulmonary complications include massive lobar collapse due to mucus plugging of a central airway, pneumonitis, atelectasis, and a combination of one or more of these or other less common problems that results in respiratory insufficiency.

Because of the high incidence of these complications and their associated costs such as prolonged hospital stay and mortality, substantial effort has been made during the 20th century to predict which patients are at increased risk for developing such complications and to identify techniques that can be used to prevent them. This article will focus on methods that are currently used to predict which patients are at increased risk for postoperative pulmonary complications and mortality.

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Pathophysiology of Postoperative Respiratory Complications

A prescient commentary in 1910 by W. Pasteur[9] pointed the direction to our current understanding of the etiology of postoperative pulmonary complications. He noted that "when the true history of postoperative lung complications comes to be written, active collapse of the lung, from deficiency of inspiratory power, will be found to occupy an important position among determining causes."[9] Most postoperative pulmonary complications develop as a result of changes in lung volumes that occur in response to dysfunction of muscles of respiration and other changes in chest wall mechanics. Abdominal and thoracic surgical procedures cause large reductions in vital capacity and smaller but crucial reductions in functional residual capacity (FRC), which has been recognized for decades as the single most important lung volume measurement involved in the etiology of respiratory complications.[10] Although no consistent changes occur in FRC after nonabdominal, nonthoracic surgery, FRC decreases after lower abdominal operations by 10 to 15%, by 30% after upper abdominal operations, and by 35% after thoracotomy and lung resection.[11–16] Other factors that

decrease FRC include the supine position, obesity, the presence of ascites, the development of peritonitis, and general anesthesia.

The other important element in the etiology of postoperative respiratory complications is the closing volume (CV), which is the lung volume at which the flow from the dependent parts of the lungs stops during expiration because of airway closure. Factors that promote an increase in CV include advanced age, tobacco use, fluid overload, bronchospasm, and the presence of airway secretions.

Under normal circumstances, FRC is about 50% and CV is about 30% of total lung capacity. When FRC is reduced or CV is increased, portions of the lung are subject to premature airway closure and atelectasis. This causes ventilation-perfusion mismatch resulting in hypoxemia and promotes the trapping of secretions resulting in pneumonitis, all of which may combine to cause respiratory insufficiency.

Thoracotomy and Lung Resection

The incidence of postoperative pulmonary complications after thoracotomy and lung resection is about 30% and is related not only to the removal of lung tissue but is also caused by alterations in chest wall mechanics due to the thoracotomy itself.[17–21] All spirometric measurements fall precipitously immediately postoperatively and do not return toward normal until 6 to 8 weeks postoperatively.[16]

Knowledge about the utility of preoperative assessment of the lung resection candidate was first developed in the 1950s and further refinement has taken place since then (Table 1). Early methods of evaluating risk included the measurement of bellows function of the lungs such as maximum voluntary ventilation and FRC.[22] The latter continues to be important for this purpose. Air flow parameters that are useful include FEV_1 and forced expiratory flow rate in the middle 50% of the forced expiratory flow curve.[23,24]

Because raw spirometric values are relatively inaccurate for surgical candidates at the far ends of the body mass spectrum, further refinement of these measurements has included expressing them as a percentage of predicted based on patient age, sex, and height.[22,24,25] The calculation of postoperative predicted values for both spirometric raw numbers and percentage of predicted values has further increased the accuracy of spirometry as a preoperative tool for evaluating pulmonary risk preoperatively.[25–27] This calculation is usually performed by estimating the number of functional lung segments that will remain postoperatively. Quantitative ventilation-perfusion scans used to assess regional lung function have aided considerably in the calculation of predicted postoperative spirometric function in patients who are considered borderline candidates for operation based on standard techniques.[28,29]

In addition to these standard methods, other measures of gas exchange and oxygen consumption have also proved useful in the preoperative assessment of risk. These include clinical assessments such as the 6-min walk distance and stair climbing effort and laboratory measures of exercise capacity such as maximum oxygen consumption during exercise ($\dot{V}O_2$max).[30–33] All have shown some promise in the prediction of postoperative pulmonary complications and, in some settings, postoperative mortality. Measurement of gas exchange capacity using diffusing capacity of the lung for carbon monoxide (DLCO) has proved to be an independent and useful means of estimating operative risk for patients undergoing major lung resection. Preoperative raw values or values expressed as a percent of predicted (DLCO%) as well as calculated postoperative values expressed as a percent of predicted function have all been shown to be useful, although the best value to use is the calculated postoperative DLCO expressed as a percent of predicted (ppoDLCO%).[26,34,35] In patients preselected as adequate candidates for lung resection on the basis of spirometry, the risk of pulmonary complications is best defined by patient age and ppoDLCO%.[35] A direct comparison between the use of DLCO% and $\dot{V}O_2$max revealed that DLCO% was a better predictor of pulmonary complications after lung resection.[21]

There have been important advances in the selection and postoperative care of the lung resection patient since the time most of the data noted previously were derived. Postoperative analgesia with epidural catheters or patient-controlled delivery devices has substantially reduced surgical pain. Vigorous pulmonary toilet exercises are used more routinely and frequently. Experience in lung volume reduction surgery and lung transplantation has increased our knowledge of how to treat critically ill patients with end-stage emphysema. There have also

Table 1—*Preoperative Tests for Assessing Pulmonary Risk Prior to Major Lung Resection*

Test	Value Range for Low-risk Patients
FEV_1%	> 60 %
DLCO%	> 60 %
ppoFEV_1	> 800 mL
ppoFEV_1%	> 40 %
ppoDLCO%	> 40 %
$\dot{V}O_2$max during exercise	> 15 mL/kg/min

been changes in the way in which lung resection operations are performed. The use of muscle-sparing thoracotomy reduces postthoracotomy pain, retains shoulder girdle muscle strength, and may permit improved spirometric function in the early postoperative period compared with a standard lateral thoracotomy.[17,36] Further improvements such as these may be evident with additional experience using thoracoscopic lung resection techniques.

At the present time, the risk of postoperative pulmonary complications in the candidate for lung resection should be evaluated with age and performance status during the initial history and physical examination. Based on the extent of planned lung resection, postoperative predicted spirometry and diffusing capacity are calculated (Table 1). For high-risk patients, an additional assessment of $\dot{V}O_2$max may be useful. Conclusions about the utility of muscle-sparing and thoracoscopic approaches await further data.

Cardiac Surgery

The incidence of pulmonary complications after cardiac surgical procedures is high and includes pneumonitis, bronchospasm, or lobar collapse in 40%, prolonged mechanical ventilation in 5 to 10%, and generalized respiratory dysfunction in most patients who undergo cardiopulmonary bypass.[37–39] The etiology of pulmonary complications in patients who undergo cardiac surgery has some factors that are similar to those that have been identified for pulmonary complications that develop after lung resection, specifically alterations in chest wall mechanics due to the incision. FRC is decreased by nearly 20% at the time of hospital discharge but is normal at 3 months after the operation. Interestingly, whether an internal mammary artery is used for bypass grafting has an important impact on respiratory function postoperatively. Increasing age and the use of an internal mammary artery graft have significant and independent negative impacts on spirometric values postoperatively.[40,41] In contrast to lung resection patients, however, the prediction of pulmonary complications after cardiac surgery is not aided by preoperative measurement of lung volumes and flows.[37]

Two unique factors contribute to the development of pulmonary complications after cardiac surgery. The first of these is the use of topical slush to protect the myocardium, which results in phrenic nerve paralysis in $> 30\%$ of patients compared with an incidence of $< 5\%$ in patients in whom no topical slush is used. The use of slush is also associated with an incidence of left lower lobe collapse of $> 80\%$ compared with only 32% in patients in whom no slush is used.[42]

The other unique factor that is associated with the development of pulmonary complications is the use of cardiopulmonary bypass. Within 24 h of surgery, there is a reduction in arterial oxygen tension of $> 30\%$, an increase in the alveolar-arterial oxygen gradient of $> 150\%$, and an increase in the pulmonary shunt fraction from a baseline of 3% to 19%. These changes only partially resolve by the end of the first postoperative week and eventually return to baseline values after 6 weeks.[39] The only predictor of this complication is a preoperative abnormality of the alveolar-arterial oxygen gradient. The presumed etiology of this profound dysfunction is the activation of a multitude of inflammatory mediators in addition to the factors mentioned above.

The overall preoperative assessment of pulmonary risk in a patient who is to undergo cardiac surgery is based more on the planned operation and less on the patient's preoperative status than for any other preoperative assessment. Issues of critical importance other than patient age and performance status are the choice of conduit if the patient is having coronary artery bypass grafting, the technique used for myocardial protection, and possibly the duration of cardiopulmonary bypass. Whether the minimally invasive approaches to bypass grafting and valve repair or replacement will reduce the incidence of postoperative pulmonary complications is as yet unknown.

Esophagectomy

Postoperative pulmonary complications occur in 25 to 50% of patients after esophagectomy.[43–45] These complications arise from a number of factors, including the type of incision used, the extent of mediastinal dissection, the development of a recurrent laryngeal nerve injury that may impair coughing efficiency postoperatively, and the presence of an intrathoracic reconstructive organ or pleural effusion that may directly impair ventilation in the early postoperative period.

The risk of pulmonary complications after esophagectomy is predicted on the basis of a number of preoperative factors, including patient age, spirometric values, diffusing capacity, performance status, nutritional status, and a diagnosis of COPD.[43–45] Intraoperative factors also strongly predict the likelihood of pulmonary complications. An increase in complications is associated with an increased volume of blood loss, use of the substernal rather than the posterior mediastinal route for esophageal reconstruction, and routine use of ventilatory support

rather than early extubation postoperatively.[43,44,46] The type of incision used to perform the resection is also a predictor of the likelihood of postoperative pulmonary complications. Use of an isolated left thoracotomy results in fewer complications than does an Ivor Lewis approach combining a right thoracotomy and laparotomy. The Ivor Lewis approach is associated with fewer complications than is a transhiatal approach, in which a laparotomy and cervical incision are performed and no thoracotomy is necessary.[44,47] The development of pulmonary complications is associated with a sevenfold increase in the risk of operative mortality, and pulmonary complications account for 40 to 60% of operative mortality.[43–45,48]

Because of the high incidence of pulmonary complications and associated operative mortality after esophagectomy, a thorough preoperative evaluation of pulmonary risk is appropriate in candidates for esophagectomy. The evaluation should include a general assessment of age, performance and nutritional status, measurement of spirometric values, and an assessment of diffusing capacity. Knowledge of the planned approach to resection and the route to be used for reconstruction will also provide useful information regarding the risk of postoperative pulmonary complications.

Abdominal Surgery

The incidence of pulmonary complications after abdominal surgery is about 30%, a frequency that is high enough to have stimulated considerable research into the etiology of this problem.[49–53] In addition to dysfunction of abdominal wall musculature, the supine position, the development of ascites, and other factors that reduce FRC postoperatively after laparotomy, abdominal surgery has the unique propensity to impair diaphragmatic function, an effect that further contributes to the reduction in FRC. Transdiaphragmatic pressure decreases by almost 70% on the first postoperative day and does not return to normal until at least 1 week postoperatively.[54] Adequate relief of postoperative pain does not reduce this impairment that appears to result from dysfunction of the diaphragm itself rather than from phrenic nerve or central neural sources. Upper abdominal operations are associated with substantially worse diaphragmatic function postoperatively than are lower abdominal operations, and the risk of postoperative pulmonary complications is accordingly higher by a factor of 1.5.[50]

The accurate preoperative prediction of pulmonary risk associated with abdominal surgery has been somewhat elusive. The use of spirometry to assess which patients are at greatest risk has enjoyed widespread popularity, but its predictive value when used routinely is unproved.[55] Clinical factors that have been shown to be useful in the prediction of postoperative pulmonary complications include a history of smoking, chronic bronchitis, airflow obstruction, obesity, and a prolonged preoperative hospital stay.[50,56,57] The presence of colonizing bacteria in the stomach and the use of nasogastric intubation increase the specific risk of postoperative pneumonia.[50,58] Smaller incisions and the use of laparoscopic techniques promise to reduce the incidence of pulmonary complications by preventing substantial reductions in pulmonary function postoperatively, but the data supporting these outcomes are scant at the present time.[59] The most important predictive factors appear to be the overall condition of the patient (based on the classification of the American Society of Anesthesiologists) and patient age.[52]

Based on available information, the preoperative evaluation of pulmonary risk in the candidate for abdominal surgery should include an assessment of patient age, general performance status, relative weight, pulmonary comorbid conditions, the planned operation, and the incision that is to be used. Spirometry is indicated in patients in whom severe pulmonary dysfunction is evident as a means to assess whether a period of pulmonary rehabilitation is indicated to improve the preoperative pulmonary condition prior to an elective operation.

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