Acta Biomed 2006; 77; 69-74

Review

Respiratory effects of surgery and pulmonary function testing in the preoperative evaluation

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Abstract. Advanced age, smoking habit, obesity or malnutrition, the coexistence of hypercapnia, bronchospasm or bronchial hypersecretion, the lack of pre-operative preparation and/or a prolonged duration of anaesthesia can negatively influence respiratory function in patients undergoing abdominal or thoracic surgery. Spirometric testing of pulmonary function is recommended in patients with a history of tobacco use or dyspnoea who are considered for cardiac or upper abdominal surgery and for all patients who are candidated for lung resection. Spirometry can provide cut-off values of acceptable risk in patients that are candidated for abdominal and thoracic surgery. At-risk patients having resective lung surgery should undergo a split lung function study with quantitative lung scanning or computed tomography in order to estimate the function of residual parenchyma after surgery. In patients with borderline estimated values, a cardiopulmonary exercise test is useful to further stratify surgical risk. (www.actabiomedica.it)

Key words: Abdominal and thoracic surgery, pulmonary function tests, preoperative assessment, spirometry

Introduction

Abdominal and thoracic surgery are associated with the risk of pulmonary complications, which are increased in patients with respiratory diseases. Pulmonologists are frequently involved, therefore, in the preoperative physiologic assessment of patients who are considered for these surgical procedures.

In the last decades, the role of lung function testing in predicting post-operative morbidity and mortality has been widely discussed (1-9) and some preoperative evaluation protocols have been proposed (4, 5, 7-9).

This review deals with the respiratory effects of extra-thoracic and thoracic surgical operations and with lung function testing that is requested before these procedures. Moreover, an evidence-based approach to the high-risk patient is provided.

Respiratory effects of extra-thoracic and thoracic surgery without lung resection

Respiratory function can be affected by both extra-thoracic and thoracic surgical operations, even when the procedure does not require lung parenchyma resection. Post-operative pulmonary complications, such as atelectasis or pneumonia can affect from 6% to 10% of subjects without coexistent pulmonary disease (10). This percentage increases in patients with respiratory diseases, and may vary between 25% and 90% according to different reports, even if mortality due to respiratory causes is rare after extra-thoracic or non-resective thoracic surgery (10).

The effects of extra-thoracic and non-resective thoracic operations on respiratory function rely on many factors (Tab. 1). First of all, the coexistence of pulmonary disease with hypercapnia, bronchospasm

Table 1. Factors interfering with the effects of extra-thoracic or non resective thoracic surgery on lung function

Patient's characteristics
- Advanced age
- Smoking habit (>20 packs/year)
- Obesity or malnutrition
Coexistence of pulmonary diseases
- Hypercapnia
- Bronchospasm
- Bronchial hypersecretion
Surgical site
- Upper Abdomen
- Lower Abdomen
- Thorax
Surgical Procedure
- Lack of pre-operatory preparation
- Emergency procedure
- Type of anaesthesia
- Duration of the operation (> 3-4 hours)

or bronchial hypersecretion, increases the risk of respiratory complications (9, 10). Moreover, some patient characteristics, such as advanced age, smoking habit (the risk is high if the patient smokes more than 20 packs/year) and obesity or malnutrition may raise respiratory complications (10). However, advanced age is not an absolute contraindication to surgery, especially if the elderly patient is in good general and respiratory conditions (10).

Other operative risk factors include the absence of pre-operative preparation, emergency procedure, duration of procedure (the incidence of post-operative pulmonary complications increases for operations lasting more than 3-4 hours) and the type of anaesthesia: general anaesthesia is normally less safe than epidural anaesthesia (9, 10). Long-acting neuromuscolar blocker pancuronium may raise the incidence of pulmonary complications, if compared to the short-acting atacurium or vecuronium (11).

The site of the surgical incision is crucial, as far as respiratory complications are concerned. Thoracotomy or laparotomy procedures, especially on the upper abdomen, can induce a negative effect on respiratory function, when compared to any peripheral procedure. Among extra-thoracic operations, those requiring an upper abdomen incision can cause major respiratory effects, which are comparable to those of thoracic operations. Furthermore, the incisions that cross the abdominal muscles cause greater reduction in Vital Capacity (VC) than those that follow the muscular bundle course (10).

Moreover, all abdominal operations can determine significant, even if temporary, reduction of diaphragmatic motility (12). The risk of post-operative pulmonary complications decreases as the surgical incision is distanced from the diaphragm (3). Since lateral thoracotomy requires the incision of the intercostal muscles and the introduction of a pleural drain, it induces pleural effusion and post-operative pain and can impair thoracic compliance. Thoracotomy can decrease respiratory function for some weeks. In patients without pulmonary disease, after thoracotomy, the VC can decrease to 60-70% of the pre-operative value, recovering the baseline value from one to two weeks, even if the restrictive defect can last longer, if thoracic pain persists (13).

The effects of thoracotomy are amplified by the coexistence of a pulmonary disease. In patients with obstructive or restrictive ventilatory defects, thoracic pain due to thoracotomy inhibits the capability of performing both deep breathing and effective coughing, thereby inducing atelectasis, bronchial mucous retention and worsening of gas exchange (10). On the other hand, lung biopsy through small thoracotomy usually has scarce respiratory effects, since the surgical incision is minimal and the resected lung parenchyma is very small. Therefore, lung biopsy procedures have few contraindications, such as haemodynamic instability and serious haemocoagulative alterations.

Heart-surgery procedures usually require median sternotomy, which is functionally better tolerated than lateral thoracotomy, since it preserves the pleural space. After cardiac surgery, the respiratory function is generally well preserved, except for a transitory reduction in pulmonary volumes. However, a prolonged cardio-pulmonary bypass can damage blood cells, which aggregate and are filtered by the pulmonary microcirculation, occasionally inducing the so-called "pump-lung syndrome", that is characterized by an increased venous mixture and a reduction in the diffusing capacity of the lung for carbon monoxide (DL_{CO}) (10).

Lung function evaluation in extra-thoracic and non resective thoracic surgery

Lung function testing is not usually considered as a tool to evaluate patients candidated for extra-thoracic and non-resective thoracic surgery. However, spirometry is mandatory in patients that are heavy smokers. Moreover, spirometry associated with blood gas analysis are usually requested in patients with a history of chronic pulmonary diseases or complaining of inexplicable dyspnoea or cough. In patients with chronic obstructive pulmonary disease, the degree of bronchial airflow obstruction is related to the risk of post-operative respiratory complications. On the other hand, in patients with other chronic respiratory disease, the relationship between pulmonary damage and post-operative risk is not well defined.

In any case, a significantly reduced value of Forced Expiratory Volume at 1st second (FEV_1) when compared to the predicted value, is considered as a prognostic value for an increase in post-operative risk even if it does not exclude surgery. In particular, it has been reported that patients with a FEV_1 value less than 1 litre undergoing non-thoracic surgery are more likely to need postoperative ventilation if, with dyspnoea at rest, their arterial partial pressure of oxygen (PaO_2) is less than 70 mmHg or, if not dyspnoic at rest, their PaO_2 is less than 45 mmHg (14). Another study reported that patients with FEV_1 less than 1.2 litres undergoing non thoracic surgery had a 37% incidence of postoperative pulmonary complications, excluding atelectasis, and had a 47% 2-yr mortality rate (15). In a large retrospective cohort study of patients having non- laparoscopic abdominal surgery, Fuso et al (16) used logistic regression analysis to determine independent predictors of respiratory failure, pneumonia, pleural effusion, and pneumothorax. The authors found that the two variables associated with the highest odds ratios were FEV_1 less than 61 % of the predicted value and PaO_2 less than 70 mm Hg.

The assessment of the arterial partial pressure of carbon dioxide ($PaCO_2$) may provide further information on the pre-operative evaluation of patients with respiratory disease. An elevation in $PaCO_2$ values greater than 6.7 kPa (50 mmHg) is associated with the development of major post-operative problems in patients undergoing coronary cardiac or vascular surgery (17). On the other hand, most patients with $PaCO_2$ greater than 45 mmHg undergoing non-cardiothoracic surgery have an uneventful postoperative course (14).

Respiratory effects of resective thoracic surgery

Advanced age, smoking habit, obesity or malnutrition, the coexistence of hypercapnia, bronchospasm or bronchial hypersecretion, and the lack of pre-operative preparation and/or a prolonged duration of anaesthesia can negatively influence respiratory function in patients undergoing resective thoracic surgery (9, 10).

The effects of pulmonary resection on respiratory function also depend on pre-operative lung function and on functional features and size of the removed lung parenchyma. The removal of non-functional lung tissue, such as a bulla, may cause an improvement or at least no deterioration in lung function. Moreover, some surgical procedures reduce secretions and purulent exudates, such as in patients undergoing lung resection for bronchiectasis. The removal of a benign tumour may allow the remaining lung to re-expand, such as the thickened pleura decortication. But in most patients, thoracic surgery results in some function impairment.

As expected, lobectomy shows less functional consequences than pneumonectomy. After lobectomy, the remaining lobes on that side rapidly expand to fill the vacant space, so that only a modest reduction in VC, in Maximal Voluntary Ventilation (MVV) and in the DL_{CO} occur. After surgery, the adaptation of the remaining lobe may take up to three months (10). The entity of the functional reduction depends on the removed lobe; the lobectomy of the middle lobe, constituted by two segments, has a smaller functional impact than the lobectomy of the right inferior lobe, constituted by five segments. After pneumonectomy, a space remains which is partly filled by mediastinal displacement and ascent of the diaphragm. Pleural fluid usually collects and replaces the pneumothorax. In spite of this, ventilatory capacity after pneumonectomy may be surprisingly good. If the parenchyma of

the remaining lung is normal, blood gases remain in the normal range both at rest and during exertion. Only pulmonary arterial pressure, which is normal at rest, may increase during exertion (10).

Lung function evaluation in resective thoracic surgery

The pulmonary function evaluation in patients undergoing resective thoracic surgery begins with spirometry, which should be performed when the patient is clinically stable and receiving maximal bronchodilator therapy. Patients with a FEV_1 value after a bronchodilator less than 2 liters (in adult males) or less than 50 percent of the predicted value are at risk for pneumonectomy. Similarly, a 60% of the predicted value of DL_{CO} or a 50% of the predicted value of MVV is risky for patients considering pneumonectomy. In patients candidated for lobectomy, FEV_1 value greater than 1.5 litres, corresponding approximately to 60% of the predicted value, is considered as a safe lower limit (4).

A blood gas analysis is requested in patients with a history of chronic pulmonary diseases or complaining of inexplicable dyspnoea or cough before being considered for resective lung surgery. Preoperative hypoxemia, an arterial oxygen saturation (SaO_2) less than 90%, has been associated with an increased risk of postoperative complications (18). Moreover, although the presence of hypercapnia, defined as a $PaCO_2$ value greater than 45 mmHg, is not considered as an independent risk factor for increased perioperative complications, further physiologic testing is advised for patients undergoing resective lung surgery (4). Table 2 lists the criteria used in estimating post-operative risk in lung resective surgery.

At-risk patients require a closer diagnostic examination before being submitted to surgery in order to estimate the likely post-resection pulmonary reserve. A quantitative lung scan, using either inhaled radioactive xenon gas for ventilation or ^{99m}Technetium macroaggregated albumin for assessing blood flow, allows the calculation of the functional remaining parenchyma after surgery and the predicted post-resection FEV_1 value. Correlations between the predicted and observed post-resection FEV_1 values have proved to be good, although errors tend to underestimate postoperative function (19). Moreover, the estimates were less precise for patients who underwent lobectomy compared with those who underwent pneumonectomy (19). Quantitative computed tomography gave comparable results to those obtained by perfusion lung scanning in predicting post-operative lung function (20). An estimated post-operative FEV_1 greater than 40% obtained by any method is widely accepted as a predictor of average risk for complications (7).

If calculation of the post-operative lung function shows borderline values, the patients should perform a cardiopulmonary exercise test. The exercise test is used to stress the entire cardiopulmonary and oxygen delivery system in order to assess the functional reserve that can be expected after pulmonary resection. Risk for surgery complications is stratified by the maximal

Table 2 . Criteria for estimating the post-operative risk in lung resective surgery

Lung Function Test	Parameters	Increased Risk	High risk
Spirometry	FEV_1	< 50 % of the predicted value or < 2 Litres	< 1 Litre
	MVV		< 50 % of the predicted value
Diffusion Capacity	DL_{CO}	< 60 % of the predicted value	
Blood Gas Analysis	SaO_2	< 90%	
	$PaCO_2$	> 45 mm Hg	

FEV_1 = Forced expiratory volume in 1 second
MVV = Maximum voluntary ventilation
DL_{CO} = Diffusing capacity of the lung for carbon monoxide
SaO_2 = Arterial oxygen saturation
$PaCO_2$ = Arterial partial pressure of carbon dioxide

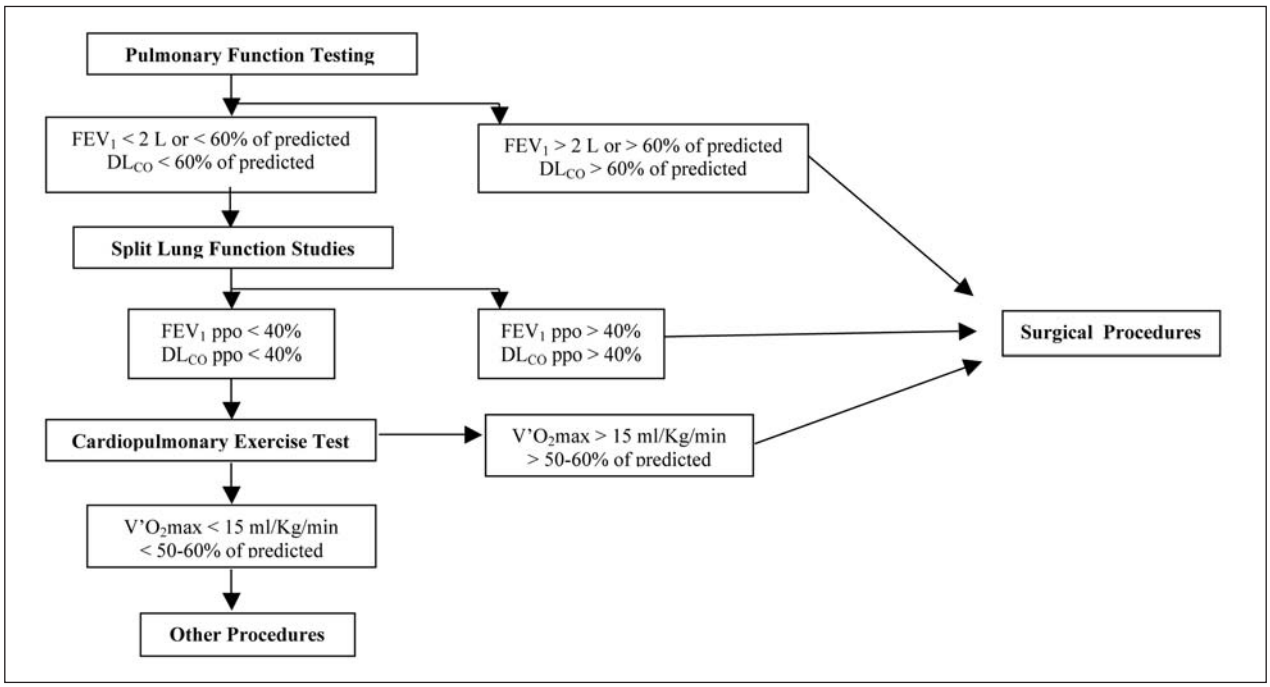

Figure 1. Algorithmic approach to the physiological assessment of patients candidated for lung resection.
FEV_1 = Forced expiratory volume in 1 second
DL_{CO} = Diffusing capacity of the lung for carbon monoxide
$V'O_2$ = Maximal oxygen uptake
ppo = predicted post-operative value

oxygen uptake ($V'O_2max$). Patients with a pre-operative $V'O_2max$ greater than 20 mL/kg/min are not at increased risk for complications or death (4). On the other hand, patients with a pre-operative $V'O_2max$ lower than 10 mL/kg/min show a very high risk for post-operative complications or death (4). Moreover, a pre-operative $V'O_2max$ lower than 15 mL/kg/min indicates an increased risk of peri-operative complications(4, 8). Figure 1 shows an algorithmic approach to the physiological assessment of patients candidated for lung resection.

Conclusions

Current guidelines do not indicate pulmonary function testing in patients without evidence of lung disease at physical examination who are considered for non-thoracic surgical procedures. Testing of pulmonary function by spirometry is recommended for patients with a history of tobacco use or dyspnoea who are considered for cardiac or upper abdominal surgery and for all patients who are candidated for lung resection. Blood gas analysis can provide further information on the pre-operative evaluation of these patients.

In patients candidated for extra-thoracic and non-resective thoracic surgery a FEV_1 value equal to or less than 1 litre or less than 61 % of the predicted value, is considered as a predictive value of an increase in post-operative risk, even if it does not exclude surgery. Moreover, PaO_2 values less than 70 mmHg or $PaCO_2$ values greater than 45 mmHg are associated with an increase in post-operative risk.

For patients undergoing lung resection, low mortality and pulmonary complications rates have been associated with a preoperative FEV_1 value greater than 2 L or 80% of the predicted value and greater than 1.5 L or 60% of the predicted value in the case of pneumonectomy or lobectomy, respectively. A condition of hypoxemia and/or hypercapnia is also reported as a risk factor for postoperative pulmonary complications. At-risk patients are recommended to undergo split

lung function studies with quantitative lung scanning or computed tomography to estimate the residual parenchyma function after surgery. In patients with borderline estimated values, a cardiopulmonary exercise test is useful to stratify further risk. A V'O2 max value less than 15 mL/kg/min is associated with increased mortality and other non surgical procedures are recommended.

Acknowledgements

We gratefully acknowledge the help of Dr Carolyn Maureen David in preparing the manuscript.

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Accepted: 24th May 2006
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