Is the reduction of forced expiratory lung volumes proportional to the lung parenchyma resection, 6 months after pneumonectomy?*†

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Abstract

**Objectives**: To preoperatively estimate the degree of first-second forced expired volume (FEV1) and forced vital capacity (FVC) reduction 6 months after pneumonectomy, according to the preoperative performed spirometry and bronchoscopy, and to estimate if the expected postoperative values of FEV1 and FVC are in accordance with the actual values. **Methods**: Thirty-five patients, who underwent pneumonectomy for non-small cell lung cancer between 1996 and 1999, were included in the perspective study. All patients had total or near total bronchial obstruction at preoperative bronchoscopy. Patients were divided into three groups according to the preoperative bronchoscopy findings: Group I, obstruction of the main bronchus (six patients); Group II, obstruction of a lobar bronchus (19 patients); and Group III, obstruction of a segmental bronchus (10 patients). The estimation of the percent reduction of FEV1 and FVC has been made according to the formula: percent reduction = (no. of bronchopulmonary segments to be resected − no. of obstructed segments) × 5.26%. **Results**: The mean overall actual percent reduction of FEV1 and FVC differed significantly from the expected mean overall percent reduction of FEV1 and FVC (P = 0.000 and P = 0.001, respectively). The actual values were lower than the predicted values using the given formula. In group and subgroup analysis, the mean actual percent reduction of FEV1 and FVC differed significantly from the mean expected percent reduction of FEV1 and FVC in Groups I and II of patients (P < 0.01), but no significant differences were observed in Group III of patients (P > 0.05). No significant differences between expected and actual mean percent reduction of FEV1 and FVC was also observed in patients of Groups I and II, when lung or lobar atelectasis, respectively, was noted at preoperative chest X-ray (P > 0.05). **Conclusions**: Only when a segmental bronchus was obstructed at the preoperative bronchoscopy or when lobar or lung atelectasis was the result of the main or lobar bronchus obstruction, the estimated, using the proposed formula, expected percent reduction of FEV1 and FVC values were close to the actual postoperative percent reduction of FEV1 and FVC. © 2002 Elsevier Science B.V. All rights reserved.

**Keywords**: Pneumonectomy; Pre- and postoperative evaluation; Pulmonary function testing; Prediction of postpneumonectomy pulmonary function; Forced expiratory lung volume; Lung perfusion scan

1. Introduction

Predicting postoperative pulmonary function is an important step in the preoperative evaluation of the candidates for major lung resection, especially pneumonectomy [1–5]. Spirometry, mainly the parameters first-second forced expired volume (FEV1) and forced vital capacity (FVC), as actual values in millilitres (ml) and as percent of the predicted value for the age and the gender of the patient, are the principal determinants of the respiratory condition [1–5]. The majority of patients undergoing lung resections are tobacco users and they have influenced preoperative respiratory function at spirometry [1,3,5,6]. Only a small percentage of candidates for lung resection have preoperatively normal lung function, permitting the thoracic surgeon to proceed for pneumonectomy, taking into account only spirometric results [5]. Expected postoperative respiratory function depends on the amount of lung parenchyma to be resected, in conjunction with the preoperative amount of non-functioning lung parenchyma, because of bronchial obstruction and infiltration from the responsible neoplasm and the involvement of lung parenchyma areas from coexisting lung disease [2,3,5,6].

Many studies, in the recent and past literature, discuss about how the surgeon could have strong documents preoperatively, for an accepted postresection pulmonary function. Simple and complex tests (bronchspirometry, cardiopulmonary stress test, diffuse lung capacity for carbon...
2. Material and methods

2.1. Patient selection — preoperative and postoperative estimation

The study was prospective, including 35 patients who underwent pneumonectomy for non-small cell lung cancer, between 1996 and 1999. The accepted criteria for including a patient in the study were: (1) the absence of development of serious postoperative complications; (2) the absence of preoperative documented cardiac disease; (3) the elective nature of the operation performed; (4) the absence of any evidence of local recurrence or metastasis in the mediastinum or elsewhere in the body, 6 months after the operation. We estimated the degree of bronchial obstruction, giving exact information about the elimination of the cross-sectional diameter of the involved bronchus, by fiberoptic bronchoscopy. Only patients who were found to have total or near total bronchial obstruction (more than 80% of the cross-sectional diameter, independent of the bronchial size) were included in the study. All patients were estimated preoperatively and 6 months postoperatively with spirometry. Ten out of 35 patients of the present study had preoperative estimation of the postoperative FEV1 using quantitative perfusion lung scan.

Patients were divided into three groups according to the preoperative bronchoscopic findings: Group I, obstruction of the main bronchus (six patients); Group II, obstruction of a lobar bronchus (18 patients) or bronchus intermedius (one patient); and Group III, obstruction of a segmental bronchus (10 patients).

Preoperative data of the 35 patients of the study is presented in Table 1.

<table>
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<tr>
<th>Table 1: Preoperative data of patients</th>
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<tr>
<td><strong>Age (years)</strong></td>
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<td>Male:female ratio</td>
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<td>FEV1 (ml)</td>
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<td>FVC (ml)</td>
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<td>Percentage of the predicted FEV1</td>
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<td>Percentage of the predicted FVC</td>
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* Predicted values for the age and the gender of the patient.

2.2. Prediction of the postoperative percent reduction of FEV1 and FVC

The expected percent reduction of forced expiratory lung volumes (FEV1, FVC) was estimated according to the formula: Expected % reduction of FEV1 or FVC = (no. of bronchopulmonary segments of the lung to be resected − no. of obstructed segments) × 5.26%.

The actual percent reduction of FEV1 and FVC was calculated as: Actual % reduction = 100 − (100 × postoperative FEV1/preoperative FEV1)

The following considerations were accepted in the study:

1. The right lung has ten bronchopulmonary segments and the left lung has nine bronchopulmonary segments. The right upper lobe has three bronchopulmonary segments, the left upper lobe has four bronchopulmonary segments, the right middle lobe has two bronchopulmonary segments and both, the right and left lower lobe, have five bronchopulmonary segments.

2. All bronchopulmonary segments are equal in volume and subsequently each segment represent the 100:19 = 5.26% of the total lung volume.

3. The reduction of FEV1 and FVC is proportional after lung parenchyma resection.

2.3. Statistical analysis

Data (mean ± SD) were analyzed using the paired samples t-test. Comparison of means between more than two groups of patients has been made using the one-way analysis of variance (ANOVA) test. Correlation between two numeric variables has been made using the Pearson correlation procedure. P values were considered significant at the 0.05 level. Statistical analysis has been made using the software SPSS (version 9.0) for windows, installed at the University of Thessaly.

3. Results

The mean actual and expected percent reduction of FEV1 and FVC in the three groups of patients, 6 months after pneumonectomy, are presented in Table 2.

The mean actual percent reduction of FVC had statistically significant difference among the three groups of patients ($F = 5.868, P = 0.007$). Regarding the least significant difference multiple comparison test, the mean value of the Group III of patients differed significantly from the mean values of Groups I and II. The mean actual percent reduction of FEV1 had no significant difference among the three groups of patients ($F = 1.705, P = 0.198$).

The mean overall actual percent reduction of FEV1 and FVC differed significantly when compared with the mean overall expected percent reduction of FEV1 and FVC ($t = 4.463, P = 0.000$ and $t = 3.593, P = 0.001$, respec-
tively); the actual values were lower than the predicted values calculated using the formula (Table 2). In group and subgroup analysis, the mean actual percent reduction of FEV1 and FVC, differed significantly from the mean expected percent reduction of FEV1 and FVC in Groups I and III of patients \((P < 0.05)\), while no differences were found between mean actual and mean expected percent reduction of FEV1 \((P = 0.922)\) and FVC \((P = 0.159)\) in Group III of patients (Table 2) As also shown in Fig. 1, only when a segmental bronchus was obstructed at the preoperative bronchoscopy (Group III), the expected percent reduction of FEV1 and FVC was in accordance with the actual percent reduction of FEV1 and FVC. In the majority of the cases, when the tumor was located in the main or a lobar bronchus resulting in total or near total bronchial obstruction, the expected mean percent reduction of FEV1 and FVC was underestimated. Retrospectively looking, we noted that, in cases where the main or the lobar bronchus was completely obstructed, with subsequent lobar or lung atelectasis development (according to the preoperative X-ray findings), the mean expected percent reduction of FEV1 and FVC had no significant difference with the mean actual postoperative percent reduction of FEV1 and FVC \((P = 0.111 \text{ and } P = 0.179, \text{ respectively})\). We observed this agreement in two out of the six patients (33.33%) of the Group I and in four out of the 19 patients (21.05%) of the Group II. In Group III of patients, the results of the formula were valid, independent of the establishment of segmental atelectasis.

The estimated FEV1 values obtained from quantitative lung perfusion scan preoperatively \((1483.62 \pm 394.62 \text{ ml})\) and the actual postoperative values \((1427.50 \pm 426.94 \text{ ml})\) had no significant difference \((P = 0.382)\) and also had an excellent correlation coefficient \((r = 0.900, P = 0.000)\) (Fig. 2). However, the accuracy of the predicted FEV1 using the quantitative perfusion lung scan deviated easily from the actual postoperative FEV1, as more bronchopulmonary segments of the lung to be resected were preoperatively obstructed (Fig. 2).

### 4. Discussion

The early consequences of pneumonectomy (within 1 year from the operation) on lung function have been examined in many past studies and FEV1 reduction after pneumonectomy was found to follow the reduction of vital capacity (VC) \([7]\). The permanent functional deficit 6 months after pneumonectomy varied from 26.7 to 40.7% for FVC and from 22.7 to 36.1% for FEV1, in many studies,
where a small number of patients (10–20) were included [8–
12]. In the present study of 35 pneumonectomy patients, similar results were observed for the reduction of forced expiratory lung volumes (38% reduction of FEV1 and 36% reduction of FVC). Many attempts have been made in the past to predict pneumonectomy pulmonary function. All these attempts failed to identify a method, other than the quantitative perfusion lung scan, which could accurately predict the pneumonectomy pulmonary function [1–6,13]. Zeicher et al., in 1995, proposed the formula: postoperative FEV1 or FVC = preoperative FEV1 or FVC × \( 1 \times 0.0526 \times s \), where \( s \) is the number of segments to be resected and 0.0526 is the result of the ratio 1:19 bronchopulmonary segments. They proposed the addition of 250 ml to the expected postoperative FEV1 for the improvement of the accuracy of their results. However, they characterized their method as ‘a worst case scenario’ for the prediction of pulmonary function after pneumonectomy. Their study included a small number of 13 pneumonectomies, where the formula was applied and the function of the segments to be removed was not taken into account in their formula [1]. In the present study, we did a modification in the formula described by Juhl and Frost and used by Zeicher et al. [1]. The obstructed segments at preoperative bronchoscopy were taken into account for the calculation of the predicted postoperative FEV1 and FVC. We also established the formula in order to base our interpretations on the ratio 1:19 bronchopulmonary segments. The results of the formula used in the present study were disappointing for its ability to predict postoperative pulmonary function, with the exception of cases where a segmental bronchus was obstructed at the preoperative bronchoscopy (10 patients) or when the total or near total obstruction of a lobar or a main bronchus resulted in lobar or lung atelectasis (six patients). In these cases, the expected values of forced expiratory lung volumes were found to be close to the actual postoperative values. These 16 cases represented about half (45,71%) of the patients referred for pneumonectomy in this study.

What is a possible explanation for the inability of the formula to predict postoperative pulmonary function, mainly when obstruction is located in the larger in diameter bronchus? There are two possible answers:

(a) Despite the estimated elimination of the bronchial diameter, more than 80% of the normal and the subsequent elimination of the cross-sectional area of up to 95% of the normal, movement of air may be possible through the remaining bronchial opening. In other instances, a near total bronchial obstruction may result in air trapping distally to the obstruction, through a valve mechanism. However, complete bronchial obstruction may be possible distally to a near total obstructed airway because of accumulation of secretions or blood coming from a tear-bleeding tumor. The flexible instrument cannot pass through the remaining bronchial opening in near total bronchial obstructions and for this reason we considered total and near total bronchial obstructions as an entity. (b) The assumption of the formula is that all bronchopulmonary segments are equal in volume, without taking into account the function of each segment separately. Some bronchopulmonary segments may be involved from coexisting lung disease to a different degree, resulting in different function (i.e. tuberculosis, emphysema, bullous disease) and this assumption may be a point of error.

Good correlation between observed and predicted FEV1, using the quantitative perfusion lung scan was obtained in many studies, where a small number of patients were included. All these studies advocated the use of the quantitative perfusion lung scan, for the prediction of postoperative FEV1, in the lung resection candidates with preoperative FEV1 values less than 2 l [2–4]. Good correlation was observed in the present study also in the 10 patients who underwent quantitative lung perfusion scan. In the recently published guidelines on the selection of patients with lung cancer for surgery by the British Thoracic Society, the authors support the use of the quantitative perfusion scan for the estimation of the postoperative FEV1 in the candidates for pneumonectomy, and the use of the formula: predicted postoperative FEV1 = preoperative FEV1 × \( [(19 - a) - b]/19 - a \) (where \( a \) is the number of obstructed segments and \( b \) that of unobstructed segments) for the lobectomy candidates [6]. The results of our study support that in selected cases, the proposed formula, based only on preoperative bronchoscopy and spirometry, can predict the pneumonectomy FEV1 and FVC.

In conclusion, we support the use of the present formula for predicting postpneumonectomy FEV1 and FVC when the total or near total bronchial obstruction is located in a segmental bronchus or when the obstruction of the main or a lobar bronchus results in lobar or lobar atelectasis. In the rest of the cases, the formula is of limited value or of no value at all and the quantitative perfusion lung scan should be used for an accurate prediction of the postoperative forced expiratory lung volumes.

References
