Uncertainties in the Expected Value for Forced Expiratory Volume in One Second after Surgery

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The purpose of this study is to understand better the reasons for the frequent unreliability of the expected value for the forced expiratory volume in one second (FEV₁) in predicting surgical results after pneumonectomy. Measurement of FEV₁ was performed in 159 patients before and after removal of one lung. Only 41 of the postoperative values for FEV₁ differed from predicted values by less than 5 percent. The reason for the discrepancy can be technical, resulting either from the method used to assess the functional pulmonary distribution (bronchospirometry or isotopic procedure) or from the data used to calculate predicted FEV₁. The discrepancy can also depend on the patient himself and particularly on the possibilities of the remaining lung to expand normally after surgery. Follow-up of patients confirmed the clinical and functional effects of erroneous predicted FEV₁.

Ventilatory impairment after pneumonectomy has worried thoracic surgeons for a long time. After reliable methods were developed to measure perfusion and ventilation distribution of the lungs, they thought that postoperative function could be foreseen and quantified.

Many investigators studied this problem, and around 1960, the predicted value for the forced expiratory volume in one second (FEV₁) appeared. This parameter is the result of a simple calculation and became rapidly popular.

In our department's pulmonary function laboratory, most of the patients undergoing surgery for pneumonectomy have been followed for over 20 years. This long-range survey shows that predicted and postoperative values for FEV₁ do not always agree.

This report tries to answer three questions: (1) What is the accuracy and validity of the method of calculation for predicted FEV₁? (2) Where can the uncertainties be, and what is their nature? (3) Do the errors have any effect on the clinical and functional postoperative results?

Materials and Methods

In 1982, we saw for their annual survey 159 patients who had undergone surgery for pneumonectomy (137 men and 22 women). The time since the surgical procedure ranged from 1 to 27 years (mean, nine years). Age at the time of surgery ranged from 21 to 71 years (mean, 53 years).

Spirometry and a measurement of pulmonary function distribution was carried out for all of them a few days before their operation. Some of the earliest patients did not have measurement of residual volume (RV).

Functional repartition was measured by different means, depending on the technical evolution: 47 patients had bronchospirometry, and 112 benefited from isotopic procedures (there were 71 multi-detector and 41 gamma camera examinations).

To make sure that they would be comparable, we considered as postoperative values those obtained one year after the pneumonectomy. As the spirometric studies and measurement of pulmonary function distribution were all performed in the same laboratory, the preoperative and postoperative results can reasonably be compared with each other.

The nature of the disease was mainly cancer, but there were also 13 tuberculosis and 13 miscellaneous processes (bronchial dilatation; benign tumors, etc). Ninety-four pneumonectomies were performed on the left and 65 on the right lung. In this work, predicted FEV₁ (Pr FEV₁) was calculated with FEV₁ measured before surgery and the ventilatory distribution between the right and left lung, using the following formula:

\[
\text{Pr FEV₁} = \text{FEV₁ before surgery} \times \frac{\text{VE of remaining lung}}{\text{total VE}} \times 100
\]

The choice of ventilation for the calculation is based on the possibility of large discrepancies between perfusion (Q) and ventilation (VE) in the malignant diseases. In such cases, FEV₁ and ventilation distributions are the closest. When calculated with perfusion, predicted FEV₁ is less reliable (see subsequent explanation).

In the 47 patients studied by bronchospirometry, the technique gives direct values for oxygen consumption (V\(\text{O}_2\)) and VE for each lung.

Seventy-one patients were studied with the multiple detector. This detector is a high-pressure xenon multiwire proportional chamber built for studies of regional ventilation and perfusion in the lung with \(^{133}\text{Xe}\). The detector's characteristics are as follows: position resolution = 12.5 mm; energy resolution at 80 keV = 30 percent efficiency at 80 keV = 35 percent; and useful array, 39 x 39 cm.

Using the gamma camera (Anger type) for 41 patients, the distribution was measured with the crystal placed behind the patient. The normal distribution with this posterior view becomes 50 percent on both sides.

At each visit of the patients, we paid special attention to the clinical state (dyspnea and general attitude) and to changes in FEV₁ and arterial blood gas levels since the pneumonectomy. Thus, we were able to compare the functional course and the morbidity of the two groups whose FEV₁ after surgery differed the most from the predicted values.

Results

Mean values for FEV₁, for the patients were as follows: preoperative FEV₁, 2,369 ± 659 ml (± SD);
predicted FEV₁, 1,487 ± 350 ml; and postoperative FEV₁, 1,507 ± 366 ml. Correlations between predicted and postoperative FEV₁ in the 159 patients were first calculated with all of the results put together, those of both bronchospirometric and isotopic methods.

Obviously, the results concerning predicted FEV₁ when measured with Vₑ distributions are the best (r = 0.74) (Fig 1). When measured with Q, r = 0.70. This justifies the choice of Vₑ distribution for the calculation.

There is a large scattering of individual results, although the slope of the regression line is not significantly different from the identity line. The different techniques of distribution measurements show that the best correlation applies to bronchospirometry (r = 0.84). Isotopic methods are obviously less reliable (for gamma camera, r = 0.68; and for multiple detector, r = 0.67) (Fig 1). Surprisingly enough, if one plots half of the preoperative against the postoperative FEV₁, the correlation coefficient is 0.75 (Fig 2).

The scattering of the dots is striking on all plots, and it led us to a critical examination of the most conflicting results. In 41 patients (26 percent) predicted and postoperative FEV₁ are almost the same, less than 5 percent apart (mean predicted FEV₁− postoperative FEV₁ = 51.39 ± 3.79 ml). Five percent can be consid-
erated as the possible error in the analysis of the pathologic results given by the apparatus. In 81 patients (51 percent), predicted and postoperative FEV₁ differ by less than one standard deviation, that is, 350 ml (mean predicted FEV₁-postoperative FEV₁ = 182.57 ± 6.6 ml).

Finally, in 37 patients (23 percent), predicted and postoperative FEV₁ disagree by more than one standard deviation. The difference is greater than 350 ml (mean predicted FEV₁-postoperative FEV₁ = 415.38 ± 12.07 ml); it can reach 400 or even 500 ml, a very large difference indeed, considering the small value of FEV₁ after pneumonectomy. This large difference is negative (that is, predicted FEV₁ < postoperative FEV₁; mean, -428.24 ± 17.69 ml) for 17 patients (11 percent) and is positive (postoperative FEV₁ < predicted FEV₁; mean, 412.54 ± 17.14 ml) for 20 patients (13 percent of the whole group).

In these 37 patients whose discrepancy between the postoperative and the predicted FEV₁ was the most conflicting (more than 350 ml apart), the clinical and functional state were compared on the short and long term. Immediate surgical and postoperative course are quite alike. Three of 17, and three of 20 patients had a more or less difficult immediate postoperative course. The median hospitalization was 25 days for both groups.

Postoperative FEV₁ was measured after one year. In the following years, few individual variations were noticed, but they did not affect significantly the classification as defined previously. In the long term, FEV₁ decreases slowly but in a parallel direction, one group with another (Fig 3). Postoperative mortality (depending mostly on the cancerous disease) and the time elapsed between surgery and death had no relation whatsoever to the FEV₁ value.

Clinical (dyspnea and general attitude) and functional (spirometry and blood gas levels) states were followed regularly after pneumonectomy, and results were gathered for comparison at two stages: (1) between the third and fifth year; and (2) ten years afterwards. Three to five years after pneumonectomy, statistics failed to exhibit a significant difference between the two groups, but on the other hand, with a classification of the patients depending on their postoperative FEV₁ absolute value, such a difference becomes obvious; for example, considering that FEV₁ is over or under 1,200 ml (35 percent of the patients' predicted FEV₁ value), p<0.02 for the clinical state, and p<0.05 for oxygen saturation.

Twelve patients reached their tenth year after pneumonectomy. In the group where postoperative FEV₁ is greater than predicted, all of the five patients are doing well clinically and functionally. In the other group where FEV₁ is smaller than predicted, five of the seven patients are hypoxemic and in poor general condition. Two suffered episodes of right-sided heart failure, two are well but their postoperative FEV₁ is particularly high, over 1,400 ml for both.

**DISCUSSION**

Other investigators' work has results similar to ours, even though they worked out several methods to calculate this predicted FEV₁ "build-up" parameter. The correlation coefficient varies between 0.63 and 0.87, depending on the method of calcula-
tion. Nevertheless, their results show the same scattering as ours, even in those having the best correlations.1,6

It is difficult to accept such a large difference between predicted and postoperative FE\textsubscript{V}, when the calculation of predicted FE\textsubscript{V} is considered a simple and logical means to foresee the postoperative value. Is the rationale of calculating predicted FE\textsubscript{V} erroneous? Does the remaining lung behave differently, depending on the patient? Can the preoperative ratio of FE\textsubscript{V}, over vital capacity (FE\textsubscript{V}/VC) be considered equal for both lungs?

**Calculation**

**Uncertainties Linked to Spirometry.** Preoperative studies and investigations must be performed a few days before surgery. At any rate, FE\textsubscript{V} may vary from one day to another in patients with chronic obstructive pulmonary disease (COPD) and even in healthy smokers. Most of our patients belong to one of these groups. The FE\textsubscript{V} may be decreased by asymmetrical forced expiratory flow of the lung when only the affected lung is obstructive (tumor; bronchial stenosis; partial destruction of parenchyma). The FE\textsubscript{V}/VC may be erroneously increased by a low VC when this maneuver is not perfectly executed. In such cases, FE\textsubscript{V}/VC is not acceptable for evaluating predicted FE\textsubscript{V}.

**Uncertainties Linked to Distribution Measurements.** Spirometric studies are executed on upright sitting patients and distribution measurements on patients lying on their back. The position of the diaphragm changes; in the supine position the diaphragm goes up, but the mobility of the right and left hemidiaphragms may differ, depending on the pathologic lesions.

For example, in 1976, we studied the pulmonary distribution of \( Q \) and \( V_e \) in 15 patients after bilobectomy by external counting.4 The functional percentage of the operated lung was compared in the two positions, erect and supine. Table 1 shows an almost 10 percent discrepancy on the operated side, depending on the position.

**Bronchoscopy and Isotopic Methods.** Bronchoscopy is the most reliable,9,10 but there is good agreement between bronchoscopic and isotopic methods.8 With nuclear tracers, dispersion is greater whether \( V_e \) or \( Q \) is used to calculate repartition, and the slope of the regression line is farther from identity. When the functional value of the affected lung is low, postoperative FE\textsubscript{V} is overestimated. This is mainly due to variations in the geometry of counting.

Some authors are satisfied with a single view, but the method favors the anterior or posterior part of the lung. Others prefer to calculate the mean of the results obtained by both views.4 Generally, the single view method is preferred by those who calculate FE\textsubscript{V} with \( V_e \) and the second method by those who calculate it with \( Q \) distribution. The best correlation between predicted and postoperative FE\textsubscript{V} was obtained by Ali et al1 using eight scintillation detectors placed behind the patient seated in the upright position. They attempted to foresee the predicted loss by a formula based on the number of segments to be removed in 91 patients (47 pneumonectomies and 44 lobectomies). The correlation coefficient was 0.87 for the former and only 0.57 for the latter, but the slope of the regression line seems to remain somewhat different from identity.

**Uncertainties Linked to the Calculation Itself.** A last objection is that all authors, including ourselves, calculate FE\textsubscript{V}, by multiplying a forced expiratory flow in an upright sitting position by a percentage of ventilation or perfusion at rest and in the supine position. Why should a forced expiratory flow have the same distribution as resting ventilation?

Considering Table 2, it appears that one can use to calculate predicted FE\textsubscript{V}, either ventilation distribution (equation 1) or, arbitrarily, half of the preoperative FE\textsubscript{V} (equation 2). Indeed, the equations' slopes and correlation coefficients are very close.

The results are such that the main parameter to appreciate predicted FE\textsubscript{V} for the 159 patients considered altogether seems to be the preoperative FE\textsubscript{V}. This may be explained, at least partly, by looking at the repartition values. Most involved lungs are still func-

### Table 1—Perfusion and Ventilation Distribution to Right Lung Depending on Position in 15 Patients after Bilobectomy

<table>
<thead>
<tr>
<th>Position</th>
<th>Perfusion, percent</th>
<th>Ventilation, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supine</td>
<td>38.4</td>
<td>41.5</td>
</tr>
<tr>
<td>Erect</td>
<td>33</td>
<td>37.8</td>
</tr>
<tr>
<td>p value</td>
<td>&lt;0.05</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

### Table 2—Calculation of Predicted FE\textsubscript{V}, and Correlation Coefficient*

<table>
<thead>
<tr>
<th>Data</th>
<th>No. of Patients</th>
<th>Equation 1</th>
<th>Equation 2</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equation 1</td>
<td>159</td>
<td>( Pr \text{ FE}_V = 0.70 \text{ PS FE}_V + 430.85 )</td>
<td>( Pr \text{ FE}_V = 0.3 \text{ presurgical FE}_V = 0.67 \text{ PS FE}_V + 181.18 )</td>
<td>0.74</td>
</tr>
<tr>
<td>Bronchospirometry</td>
<td>47</td>
<td>( Pr \text{ FE}_V = 0.91 \text{ PS FE}_V + 152.24 )</td>
<td></td>
<td>0.84</td>
</tr>
<tr>
<td>Multiple detector</td>
<td>71</td>
<td>( Pr \text{ FE}_V = 0.64 \text{ PS FE}_V + 519.91 )</td>
<td></td>
<td>0.67</td>
</tr>
<tr>
<td>Gamma camera</td>
<td>41</td>
<td>( Pr \text{ FE}_V = 0.63 \text{ PS FE}_V + 574.34 )</td>
<td></td>
<td>0.68</td>
</tr>
<tr>
<td>Equation 2</td>
<td>159</td>
<td></td>
<td></td>
<td>0.75</td>
</tr>
</tbody>
</table>

*Pr, Predicted; and PS, postsurgical.
tionally very active: $\dot{V}E$ is over 38 percent in 78 percent, and $\dot{Q}$ is over 30 percent in 70 percent of them.

To conclude, there are several reasons, mainly technical, for mistakes in the prediction of FEV$_1$ after pneumonectomy. Each one may be rather small, but they accumulate, and it is not surprising to note that the result is sometimes inaccurate; however, they may not be the only explanation of the very large discrepancies observed in 37 of the patients.

**Modifications of the Remaining Lung**

After pneumonectomy the remaining lung adjusts to the loss of part of the exchange surface by the creation of new conditions of ventilation and perfusion. The adaptation takes place during the first months after surgery, and it seems that 6 to 12 months later, the single lung comes to its definitive shape. The main changes are a progressive increase of pulmonary volume with a ratio of RV over total lung capacity (RV/TLC) remaining higher after surgery than before. These changes attest to a good adaptation to the pneumonectomy; it does not need to be, nor should it be corrected. Anthonisen et al., in studying the ventilation-perfusion ratio of the remaining lung by $^{133}$Xe, demonstrated that these changes may favor the opening of new functional areas.

The distention has been studied in the patients in whom the discrepancy between postoperative FEV$_1$ and predicted FEV$_1$ was the greatest and compared with that of the others. The patients are thus divided into the following three groups: (1) group 1, postoperative FEV$_1$ greater than predicted FEV$_1$ by more than one standard deviation; (2) group 2, postoperative FEV$_1$ smaller than predicted FEV$_1$ by more than one standard deviation; (3) group 3, the other patients.

Figure 4 shows that the distention did not occur in the second group; VC, TLC, and RV are smaller in these patients than in the others. As far as RV/TLC is concerned (Fig 5), two points should be emphasized; it was abnormally high before surgery, and even though it fell afterwards, it remained widely above normal values. This could mean that the remaining lung was previously overstretched by COPD and could not further expand after pneumonectomy. The opening of new functional areas is therefore limited.

**Asymmetrical FEV$_1$**

This possibility applies to the first group, where postoperative FEV$_1$ is much higher than predicted FEV$_1$. In 80 percent of these patients, FEV$_1$/VC one year after surgery is significantly higher (p<0.001) than before. This could be the result of an "asymmetrical FEV$_1$." Indeed, before surgery, FEV$_1$ is the addition of right and left expiratory flow. Unilateral obstruction by tumor or partially destroyed parenchyma may decrease the forced expiratory flow in a proportion that differs from that of $\dot{V}E$ or $\dot{Q}$. In some cases the asymmetry can be obvious either on roentgenographic examination (clear lung on the sick side by gas trapping during forced expiration) or in many

![Figure 4](image-url)  
**Figure 4.** Percentage of remaining VC, TLC, and RV one year after pneumonectomy (159 patients) (observed values and standard error). Groups 1 and 2, FEV$_1$ after surgery larger (group 1) or smaller (group 2) than predicted value by at least 1 SD. Group 3, Postoperative FEV$_1$ differing from predicted value by less than 1 SD.

![Figure 5](image-url)  
**Figure 5.** Ratio of RV/TLC before and after pneumonectomy in three groups of patients considered in Figure 6 (observed values and standard error).
others on the 133Xe washout curve (Fig 6). In this patient, predicted FEV₁, calculated as explained previously is without a doubt false.

Perhaps other factors could be responsible for the discrepancy between predicted and postoperative FEV₁. We made sure of the nonsignificant influence of the following: (1) overweight (5 kg or more over the centimeters above 1 meter of height); (2) pathologic sequelae of the remaining lung; (3) thoracoplasty after pneumonectomy; and (4) postoperative treatments such as radiotherapy and chemotherapy.

This study was not undertaken with the idea that patients' outcome should be guessed from predicted FEV₁ alone. In most of the recent prospective studies, several variables are considered. Nevertheless, as far as our patients are concerned, the repercussion of the discrepancy between postoperative and predicted FEV₁ on the postoperative clinical and functional course cannot be denied.

In opposition to the findings of Nakahara et al., a difference in the immediate postoperative course does not appear in the 37 patients with the most conflicting values in this series, but the poor tolerance of the pulmonary impairment in patients whose predicted FEV₁ has been overestimated cannot be questioned. The statistical significance appears when the postoperative absolute value of FEV₁ is considered. This is in agreement with the common idea that the comfort of patients with pulmonary insufficiency is seriously threatened when FEV₁ falls below a minimum value. It is true whatever the reason for its fall, whether a decrease of pulmonary volume or of expiratory flow.

Thus, there is an obvious danger in uncertainties of predicted FEV₁ before pneumonectomy when the calculation leads to an overestimation. The clinical and functional follow-up clearly points out that there is an unforeseeable chance that postoperative FEV₁ falls below the limit of 35 percent of the predicted value of FEV₁. In such cases the patient will not tolerate his pulmonary amputation for long.

**CONCLUSION**

At the end of this study, the practical conclusions are as follows: first, calculation of predicted FEV₁ is automatic. If used alone in functional prospective studies before pneumonectomy, it could lead to irrelevant conclusions and eventually be dangerous for some patients, particularly for those patients who developed large pulmonary distention before the time of surgery. After pneumonectomy, they may experience a difficult time; the "green light" of predicted FEV₁ should have been red.

Secondly, surgeons can underestimate postoperative functional values in the patients with asymmetric forced expiration before surgery. In these cases, the surgeons missed a good surgical indication.

Thus, calculation of predicted FEV₁ is a very defective approach to the postoperative state. In a pinch, it could be acceptable for patients with a normal spirogram and rather symmetrical right-sided and left-sided ventilation. This means that the more difficult the surgical indication, the more misleading the predicted FEV₁ can be.

As far as patients with difficult surgical indications are concerned, a discriminant function using several variables is a good proposition. Among data on pulmonary function, RV and RV/TLc seem essential, and a hemodynamic study was favorably reconsidered in 1985 by Brundler et al.

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