Predicting Postoperative Pulmonary Function in Patients Undergoing Lung Resection*

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Objective: Our aim was to determine the effect of lung resection on spirometric lung function and to evaluate the accuracy of simple calculation in predicting postoperative pulmonary function in patients undergoing lung resection.

Design: We reviewed preoperative and postoperative pulmonary function test results on patients who were followed in the multidisciplinary lung cancer clinic between July 1991 and March 1994 and who underwent lung resection. The predicted postoperative FEV$_1$ and FVC were calculated based on the number of segments resected and were compared with the actual postoperative FEV$_1$ and FVC.

Setting: This study was conducted at a university, tertiary referral hospital.

Patients: All patients were evaluated at a multidisciplinary lung cancer clinic and underwent lung resection by one surgeon (L.A.L.).

Measurements and main results: Sixty patients undergoing 62 pulmonary resections were reviewed. The predicted postoperative FEV$_1$ and FVC were calculated using the following formula: predicted postoperative FEV$_1$ (or FVC) = preoperative FEV$_1$ (or FVC) × (1 - (S × 0.0526)); where S = number of segments resected. The actual postoperative FEV$_1$ and FVC correlated well with the predicted postoperative FEV$_1$ and FVC for patients undergoing lobectomy (r = 0.867 and r = 0.832, respectively); however, the predicted postoperative FEV$_1$ consistently underestimated the actual postoperative FEV$_1$ by approximately 250 mL. For patients undergoing pneumonectomy, the actual postoperative FEV$_1$ and FVC did not correlate as well with the predicted postoperative FEV$_1$ and FVC (r = 0.677 and r = 0.741, respectively). Although there was considerable variability, the predicted postoperative FEV$_1$ consistently underestimated the actual postoperative FEV$_1$ by nearly 500 mL. Of the patients undergoing lobectomy, eight also received postoperative radiation therapy. When analyzed separately, patients receiving combined therapy lost an average of 5.47% of FEV$_1$ per segment resected. This contrasts with a 2.84% per segment reduction in FEV$_1$ for patients who did not receive radiation therapy.

Conclusions: This simple calculation of predicted postoperative FEV$_1$ and FVC correlates well with the actual postoperative FEV$_1$ and FVC in patients undergoing lobectomy. The predicted postoperative FEV$_1$ consistently underestimated the actual postoperative FEV$_1$ by approximately 250 mL. The postoperative FEV$_1$ and FVC for patients undergoing pneumonectomy is not accurately predicted using this equation. The predicted postoperative FEV$_1$ for patients undergoing pneumonectomy was underestimated by an average of 500 mL and by greater than 250 mL in 12 of our 13 patients. Thus, by adding 250 mL to the above calculation of predicted postoperative FEV$_1$, we improve our ability to estimate FEV$_1$ for patients undergoing lobectomy and we identify a minimal postoperative FEV$_1$ for patients undergoing pneumonectomy. Finally, combined modality treatment with surgery followed by radiation therapy may result in additive lung function loss.

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Key words: lung cancer; lung resection; pulmonary function testing

Lung cancer is the most common cause of cancer death in both men and women in the United States. It has been estimated that there will be 172,000 lung cancer deaths in 1994. Surgical resection offers the best chance for cure in patients with non-small cell lung carcinoma. However, many patients with bronchogenic carcinoma also have coexistent obstructive lung disease related to tobacco use. Coexistent obstructive lung disease increases the morbidity and mortality of lung resection. Given this increased morbidity, the best physiologic determinants to identify patients capable of safely undergoing lung resection remain controversial. Of these screening procedures, spirometry has the advantage of being widely available, easily performed, relatively inexpensive, and able to identify the degree of

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underlying lung disease. In addition, spirometry along with the anticipated amount of lung resection can be used to predict postoperative lung function.

Previous studies have examined the relationship between preoperative and postoperative FEV₁ using either simple calculation or split lung function perfusion scanning. These studies, however, are based on small sample size, two of the three were done prior to published standards for pulmonary function testing, and they often analyzed patients undergoing pneumonectomy and lobectomy as a single group. In addition, surgical techniques and supportive critical care have improved significantly since these original studies. We recently established a multidisciplinary lung cancer clinic where all patients considered for curative resection for bronchogenic carcinoma are evaluated and undergo preoperative pulmonary function testing as part of their evaluation. All operations are performed by one surgeon (L.A.L.) and follow-up care is coordinated through the same clinic. This clinic allowed us the opportunity to study the effect of lung resection on pulmonary function in a very controlled environment. We postulated that we could accurately predict postoperative lung function based on the preoperative pulmonary function test results and the amount of lung resected. To test this, we measured preoperative and postoperative spirometry on all of our patients undergoing lung resection and analyzed them to determine the effect of lung resection on pulmonary function.

Methods
Patient Selection and Pulmonary Function Testing

We identified all patients followed in the multidisciplinary lung cancer clinic between July 1991 and March 1994 who underwent lung resection. Preoperative and postoperative pulmonary functions (spirometry, DCO, and arterial blood gas) were performed on all patients who underwent lung resection. All pulmonary function testing was performed (Medgraphics Systems 1070 and 1085, Medgraphics Corporation, St. Paul, Minn) according to American Thoracic Society standards and using the normal standards as described by Morris et al. When more than one preoperative FEV₁ and FVC were available, the largest preoperative FEV₁ and FVC were used for further calculations.

Calculation of Predicted Postoperative FEV₁ and Predicted Postoperative FVC

Predicted postoperative FEV₁ and FVC were calculated as described by Juhl and Frost, based on the number of lung segments resected: predicted postoperative FEV₁ (or FVC) = preoperative FEV₁ (or FVC) × (1−0.0526X); where S=number of segments resected. Each segment is considered to represent 1/19 of the lung function (1/19=0.0526). The lower lobes were considered to have five pulmonary segments each, the right upper lobe to have three segments, the right middle lobe to have two segments, and the left upper lobe to have four segments.

Statistics

The relationships between the predicted and actual postoperative FEV₁ and FVC were calculated using linear regression. A two-sided Student's t test was used to compare the mean values of pulmonary function test results between patient subgroups.

Results

Patients

Between July 1991 and March 1994, we identified 60 patients who underwent 62 lung resections with preoperative and postoperative pulmonary function testing. There were 13 pneumonectomies (6 right, 7 left), and 49 lobectomies or wedge resections (41 lobectomies, 7 bilobectomies, and 1 wedge resection). The demographic features and pulmonary function data are shown in Table 1. There were 21 women and 39 men. The mean age of the patients undergoing lobectomy was 59 years (range, 29 to 79 years) and the mean age of the patients undergoing pneumonectomy was 64 years (range, 53 to 78 years). The postoperative pulmonary function tests were performed an average of 8.5 months after surgery for the patients undergoing lobectomy and 7.2 months for the patients undergoing pneumonectomy (range, 24 days to 5 years). The lung resections were performed for neoplastic indications in all but three cases. Of these three, one patient underwent resection for Mycobacterium kansasii infection, one for a lung abscess, and one for histoplasmosis. There were 21 adenocarcinomas, 15 squamous cell carcinomas, 3 large cell undifferentiated carcinomas, 4 carcinoids, 1 sarcoma, and 1 case of papillomatosis among the patients undergoing lobectomy. Among the patients undergoing pneumonectomy, there were ten squamous cell carcinomas, one large cell undifferentiated carcinoma, and one hemangiopericytoma. Eight of the patients undergoing lobectomy and five of the patients undergoing pneumonectomy were found to have microscopic mediastinal lymph node metastases at the time of resection and received ad-
juvant radiation therapy prior to their postoperative pulmonary function testing.

Patients Undergoing Lobectomy

For the 49 patients who underwent a lobectomy, we found a good correlation between the actual and predicted postoperative FEV$_1$ and FVC; however, predicted postoperative FEV$_1$ underestimated the actual postoperative FEV$_1$ (Fig 1). The average preoperative FEV$_1$ and FVC for the patients undergoing lobectomy were 2.49 ± 0.13 L and 3.70 ± 0.15 L, respectively. The mean actual postoperative FEV$_1$ and FVC were 2.12 ± 0.11 L and 3.24 ± 0.17 L, respectively. This reduction corresponded to a 13.4 ± 2.2% decline in FEV$_1$ or 3.27 ± 0.55% per segment resected. For FVC, this corresponded to a 12.2 ± 2.3% decline or 2.86 ± 0.58% per segment resected. Linear regression analysis revealed that the predicted postoperative FEV$_1$ and FVC correlated well with the actual postoperative FEV$_1$ and FVC ($r=0.867$ and $r=0.832$, respectively). However, as shown in Figure 1, the line of best fit for FEV$_1$ was defined by the following: actual postoperative FEV$_1$ = 0.967 × predicted postoperative FEV$_1$ + 0.265. This demonstrates that the calculation underestimates the actual postoperative FEV$_1$ by about 250 mL. For FVC, the line was defined by actual postoperative FVC = 1.20 × predicted postoperative FVC−0.172. Thus, the postoperative FVC is underestimated due to an increased slope.

Because patients with a preoperative FEV$_1$ of less than 2 L are at increased risk for lung resection, we also analyzed them separately. Patients with a FEV$_1$ of less than 2 L had a greater variability in the reduction of their postoperative FEV$_1$, but their mean reduction in FEV$_1$ did not significantly differ from those patients with a preoperative FEV$_1$ of greater than 2 L. There were 14 patients with a preoperative FEV$_1$ of less than 2 L. They had a mean reduction in FEV$_1$ of 2.03 ± 1.42% per segment resected. The 35 patients with a preoperative FEV$_1$ of greater than 2 L had a mean reduction of 3.76 ± 0.52% per segment resected ($p=0.16$).

Patients Undergoing Pneumonectomy

For patients undergoing pneumonectomy, the predicted and actual FEV$_1$ and FVC did not correlate as well as they did in patients undergoing lobectomy. The mean preoperative FEV$_1$ and FVC for patients undergoing pneumonectomy were 2.24 ± 0.52 L and 3.56 ± 0.81 L, respectively. The mean actual postoperative FEV$_1$ and FVC were 1.56 ± 0.37 L and 2.33 ± 0.57 L, respectively. This corresponds to a 29.0 ± 3.94% reduction in FEV$_1$ or 3.07 ± 0.42% per segment resected and a 33.9 ± 2.85% reduction in FVC or 3.59 ± 0.30% per segment resected. Linear regression analysis revealed that the predicted postoperative FEV$_1$ and FVC did not correlate as well

![Figure 1](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21717/)

**Figure 1.** Simple calculation of postoperative FEV$_1$ underestimates actual postoperative FEV$_1$ in patients undergoing lobectomy. The solid line represents the line of best fit using linear regression analysis ($r=0.867$), and the hatched line depicts the line of identity. As can be seen, the line of best fit is nearly parallel with the line of identity, but is displaced upwards by about 250 mL.

![Figure 2](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21717/)

**Figure 2.** Simple calculation of postoperative FEV$_1$ underestimates actual postoperative FEV$_1$ in patients undergoing pneumonectomy. The solid line represents the line of best fit using linear regression analysis ($r=0.677$), and the hatched line depicts the line of identity. As can be seen, the line of best fit is nearly parallel to the line of identity, but is displaced upwards by nearly 500 mL. No patients fall below the line of identity, and all but one of the patients are more than 250 mL above the line of identity.
with the actual postoperative FEV\textsubscript{1} and FVC (r=0.677 and r=0.741, respectively) as they did in patients undergoing lobectomy. As depicted in Figure 2, there is considerable variation in the postoperative FEV\textsubscript{1} in patients undergoing pneumonectomy. The line of best fit for FEV\textsubscript{1} was defined by the following: actual postoperative FEV\textsubscript{1} = 0.967 \times \text{predicted postoperative FEV}_1 + 0.475. Thus, the predicted FEV\textsubscript{1} underestimates the actual postoperative FEV\textsubscript{1} by nearly 500 mL. Even when a more conservative correction of 250 mL is added to the predicted FEV\textsubscript{1}, we underestimated the FEV\textsubscript{1} in all but one patient. For FVC the line of best fit was defined by the following: actual postoperative FVC = 1.027 \times \text{predicted postoperative FVC} + 0.497. Thus, the FVC was also underestimated by nearly 500 mL.

**Effect of Radiation Therapy**

The eight patients who received postlobectomy radiation therapy prior to postoperative pulmonary function testing were examined separately. These eight patients had their postoperative pulmonary function test an average of 6 months after completing radiation therapy (range, 10 weeks to 20 months). As shown in Table 2, the patients who received combined therapy had almost identical mean preoperative pulmonary function as those who had lobectomies alone. Those who received radiation therapy after lobectomy had a mean reduction in FEV\textsubscript{1} of 5.47% per segment resected. This contrasts with a 2.84% per segment reduction in FEV\textsubscript{1} for patients undergoing lobectomy who did not receive radiation therapy (p=0.08).

**DISCUSSION**

The preoperative evaluation of patients with lung cancer is a common and very important problem. It is important not only to identify those patients with potentially resectable disease, but also to identify those patients who can tolerate lung resection.\textsuperscript{3,4,9} The predicted postoperative FEV\textsubscript{1} is a frequently used criterion for defining physiologic operability.\textsuperscript{3,10,11} Unfortunately, a tolerable lower limit of postoperative FEV\textsubscript{1} is unknown and it is also unclear how accurately we can predict the actual postoperative FEV\textsubscript{1} from the preoperative FEV\textsubscript{1}. Despite these limitations, a predicted postoperative FEV\textsubscript{1} of greater than 800 mL or greater than 40% of predicted are common criteria for resectability.\textsuperscript{3,11}

Both simple calculation and nuclear perfusion scanning have been used to predict postoperative FEV\textsubscript{1}. Three previous studies have shown that the correlation between predicted and actual postoperative FEV\textsubscript{1} using perfusion scanning is no better than using simple calculation.\textsuperscript{3,5,6} However, these studies had small sample sizes, two of the three were performed prior to published standards for pulmonary function testing, they often analyzed patients undergoing pneumonectomy and lobectomy together, and they looked primarily at correlation rather than accuracy. Our aim was to examine the effects of lung resection on pulmonary function in a large patient population where variables such as the surgical technique, patient follow-up, and spirometric techniques were controlled. Furthermore, we were interested in determining if a simple calculation could accurately predict postoperative pulmonary function.

Our study shows that simple calculation based on preoperative pulmonary function studies correlates well with the actual postoperative FEV\textsubscript{1} for patients undergoing lobectomy. This calculation, however, systematically underestimates the actual postoperative FEV\textsubscript{1} for patients undergoing lobectomy by up to 2% per segment resected or 250 mL total. For patients requiring pneumonectomy, we found that using simple calculation the predicted and actual postoperative FEV\textsubscript{1} did not correlate as well as in patients requiring lobectomy. Additionally, this calculation underestimated the postoperative FEV\textsubscript{1} of patients undergoing pneumonectomy by 500 mL. In fact, the FEV\textsubscript{1} in all but one of our patients was underestimated by 250 mL or more. We propose that the prediction equation be modified by adding 250 mL to the calculation proposed by Juhl and Frost.\textsuperscript{5} This would more accurately predict the postoperative FEV\textsubscript{1} of patients undergoing lobectomy and predict a worst case scenario for patients undergoing pneumonectomy. Thus, using this calculation, more patients may be candidates for potentially life-saving lung resection.

We believe that this modification will prove to be clinically useful. For example, if a patient is being evaluated for a right pneumonectomy and has a preoperative FEV\textsubscript{1} of 1.5 L, he or she would generally get additional evaluation such as perfusion scanning or cardiopulmonary exercise testing. Using

<table>
<thead>
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<th>Variable</th>
<th>Lobectomy Alone</th>
<th>Lobectomy and Radiation</th>
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<tr>
<td>n</td>
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<td>8</td>
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<tr>
<td>Preoperative FEV\textsubscript{1}, L</td>
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<td>Postoperative FVC, L</td>
<td>3.28 ± 0.19</td>
<td>3.05 ± 0.34</td>
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<tr>
<td>ΔFEV\textsubscript{1} per segment resected, %</td>
<td>-2.84 ± 0.16</td>
<td>-5.47 ± 1.11†</td>
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<tr>
<td>ΔFVC per segment resected, %</td>
<td>-2.61 ± 0.66</td>
<td>-4.12 ± 0.18</td>
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*Values expressed as means ± SEM.†p=0.08.
our modified calculation, the predicted postoperative FEV₁ would be 0.711 + 0.250 or 0.961 L. This represents a lower limit estimate, so surgery could be offered without additional testing.

In our series, patients who received adjuvant radiation therapy had a larger drop in their pulmonary function than those undergoing lobectomy alone. Although our small patient numbers precluded a statistically significant comparison, there was a trend toward a larger fall in FEV₁. We measured lung function an average of 6 months after radiation therapy. We are therefore unable to say whether this additive loss in lung function is a transient phenomenon reflecting regional radiation pneumonitis or whether it reflects permanent loss of lung function. This is of interest, because radiation therapy is commonly prescribed as adjuvant therapy for lung cancer, but its effects on pulmonary function are not well defined.

In conclusion, our study demonstrates the value of simple calculation of predicted postoperative FEV₁ in the preoperative assessment of patients with lung cancer. Our data suggest that this calculation is improved by adding 250 mL to the predicted postoperative FEV₁. This modification should improve the accuracy of the predicted postoperative FEV₁ for patients undergoing lobectomy and serve as a worst case scenario for patients undergoing pneumonectomy. Patients whose predicted postoperative pulmonary function remains marginal will still require additional evaluation. The best additional evaluation to perform is not entirely clear. At our institution, we use cardiopulmonary exercise testing to assess resectability of the marginal patient.

REFERENCES

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