# THE EFFECT OF INCENTIVE SPIROMETRY AND INSPIRATORY MUSCLE TRAINING ON PULMONARY FUNCTION AFTER LUNG RESECTION

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***Background:*** **A predicted postoperative forced expiratory volume in 1 second ($FEV_1$) of less than 800 ml or 40% of predicted is a common criterion for exclusion of patients from lung resection for cancer. Usually, the predicted postoperative lung function is calculated according to a formula based on the number of lung segments that will be resected. Incentive spirometry and specific inspiratory muscle training are two maneuvers that have been used to enhance lung expansion and inspiratory muscle strength in patients with chronic obstructive pulmonary disease and after lung operation.** ***Methods:*** **Thirty-two patients with chronic obstructive pulmonary disease who were candidates for lung resection were randomized into two groups: 17 patients received specific inspiratory muscle training and incentive spirometry, 1 hour per day, six times a week, for 2 weeks before and 3 months after lung resection (group A) and 15 patients were assigned to the control group and received no training (group B).** ***Results:*** **Inspiratory muscle strength increased significantly in the training group, both before and 3 months after the operation. In group B, the predicted postoperative $FEV_1$ value consistently underestimated the actual postoperative $FEV_1$ by approximately 70 ml in the lobectomy subgroup and by 110 ml in the pneumonectomy subgroup. In group A, the actual postoperative $FEV_1$ was higher than the predicted postoperative $FEV_1$ by 570 ml in the lobectomy subgroup and by 680 ml in the pneumonectomy subgroup of patients.** ***Conclusions:*** **In patients undergoing lung resection the simple calculation of predicted postoperative $FEV_1$ underestimates the actual postoperative $FEV_1$ by a small fraction. Lung functions can be increased significantly when incentive spirometry and specific inspiratory muscle training are used before and after operation. (J Thorac Cardiovasc Surg 1997;113:552-7)**

The preoperative evaluation of the condition of patients with potentially resectable lung cancer may identify patients who will be unable to tolerate lung resection. However, the best physiologic determinants to identify patients capable of safely undergoing lung resection remain controversial. Preoperative pulmonary scintigraphy has been suggested as a reliable method for assessing the contribution of the lung to be resected to the overall function and for predicting postoperative ventilatory function.[1, 2] The predicted postoperative value of forced expiratory volume in 1 second ($FEV_1$) is also a frequently used criterion for defining operability.[3, 4] This procedure has the advantage of being simple to do, inexpensive, and widely available.

Usually the predicted postoperative $FEV_1$ (or forced vital capacity [FVC]) is calculated according to the formula described by Juhl and Frost,[5] which is based on the number of lung segments that will be resected. However, Zeiher and associates[6] showed that although this simple calculation, based on preoperative pulmonary function study results, correlates well with the actual postoperative $FEV_1$, it underestimates the actual postoperative $FEV_1$ by 250 ml. They proposed that the prediction equation be modified by adding 250 ml to the calculation proposed by Juhl and Frost.[5] A predicted postoperative $FEV_1$ of less than 800 ml or less than 40% of

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predicted is a common criterion for the exclusion of patients from lung resection.[3, 4] In the study done by Markos and associates[3] a predicted postoperative $FEV_1$ of less than 40% of predicted was associated with a 50% mortality rate, whereas a predicted value of more than 40% was associated with no postoperative mortality.

Incentive spirometry (IS)[7, 8] and specific inspiratory muscle training (SIMT)[9, 10] are two maneuvers that have been used to enhance lung expansion in patients with chronic obstructive pulmonary disease (COPD) and after surgery. However, neither technique has been tested extensively in the preoperative and postoperative phases of lung operations.

We therefore performed a study to determine the effect of lung resection on pulmonary function, the accuracy of predicting postoperative lung function, and the effect of preoperative and postoperative IS combined with SIMT on postoperative pulmonary function.

## Methods

**Patients.** Thirty-two patients with COPD (23 men and 9 women) 42 to 80 years old (mean plus or minus standard error of the mean 61.5 ± 1.7 years), who were candidates for lung resection, were recruited for the study. The patients were then randomized into two groups: 17 patients received SIMT and IS for 2 weeks before and 3 months after lung resection (group A) and 15 patients were assigned to the control group and received no training (group B). In group A 7 patients had a pneumonectomy (4 left and 3 right) and 10 had a lobectomy (3 had bilobectomies), whereas in group B 4 patients had a pneumonectomy (3 left and 1 right) and 11 had a lobectomy (2 had bilobectomies). The clinical characteristics, pulmonary function results, and predicted postoperative pulmonary function values of patients undergoing lung resection are summarized in Table I. All patients gave informed consent approved by the institutional review board.

**Spirometry.** Pulmonary lung function was assessed by spirometry done 2 weeks before and 3 months after the operation. The FVC and the $FEV_1$ were measured three times on a computerized spirometer (Compact, Vitalograph, Buckingham, England) and the best trial results were reported.

**Inspiratory muscle strength.** Inspiratory muscle strength was assessed by measuring the maximal inspiratory mouth pressure ($PI_{max}$) at residual volume as previously described by Black and Hyatt.[11] The value obtained from the best of at least three efforts was used.

**Training protocol.** Subjects in groups A trained daily, six times a week. Each session consisted of 1 hour of training; training began 2 weeks before lung resection and continued for 3 months thereafter. The training was done under the supervision of a physiotherapist.

**SIMT.** For the first 30 minutes of training the subjects received SIMT with a threshold inspiratory muscle trainer (THRESHOLD inspiratory muscle trainer, Healthscan). The subjects started breathing at a resistance equal to 15% of their individual $PI_{max}$ for the first week and breathed at a resistance equal to 20% of their $PI_{max}$ during the second week before the operation. After the operation the subjects started breathing again at a resistance equal to 15% of their individual $PI_{max}$ for 1 week. The resistance was then increased incrementally at 5% each session until 60% of the $PI_{max}$ was reached at the end of the first month. SIMT was then continued for the next 2 months at this level of resistance.

**IS.** In the last 30 minutes of each session the patients in group A received IS with the use of a volumetric incentive spirometer (DHD Coach) that was fitted with a one-way valve, a coaching indicator to encourage slow inspirations, and a patient goal marker. The patients were instructed to take slow maximal inspirations and to hold each breath for as long as possible. This maneuver was done at least 30 times during the 30-minute period.

**Calculation of predicted postoperative lung function.** Predicted postoperative lung function was calculated by the formula suggested by Juhl and Frost[5]: predicted postoperative $FEV_1/FVC$ = preoperative $FEV_1/FVC \times (1 - 0.0526 \times S)$, where S is the number of segments resected. The lower lobes were considered to have five segments each, the right upper lung three segments, the right middle lobe two segments, and the left upper lobe four segments.

**Data analysis.** The relationships between the predicted and actual postoperative lung function values were calculated by linear regression. Comparisons of lung function between patient subgroups and between the groups were done by two-way repeated measures analysis of variance.

## Results

The clinical characteristics and preoperative and predicted postoperative lung function test results are summarized in Table I. The mean age of the patients undergoing lobectomy was 58.4 years in group A and 62.2 years in group B, and the mean age of the patients undergoing pneumonectomy in each group was 61.9 and 66.5 years, respectively. All patients underwent lung resection because of primary lung neoplasm.

The patients in the training group (group A) showed a significant increase in inspiratory muscle strength (expressed as $PI_{max}$ at residual volume) (from 66.0 ± 2.8 cm $H_2O$ at baseline to 69.5 ± 2.4 cm $H_2O$, $p = 0.004$) after 2 weeks of training and before the operation and an even more significant increase after 3 months of training after the operation (to 81.2 ± 3.5 cm $H_2O, p = 0.0001$) (Fig. 1). On the other hand, inspiratory muscle strength was unchanged in the control group (group B) (measured only in 9 patients) before the operation

**Table I.** *Characteristics of patients undergoing lung resection*

| | | | *Preoperative value** | | | *Predicted postoperative value†* | |
|---|---|---|---|---|---|---|---|
| *Patient No.* | *Sex* | *Age (yr)* | $FEV_1$ | *FVC* | *Operation* | $FEV_1$ | *FVC* |
| | | | | **Group A** | | | |
| Pneumonectomy | | | | | | | |
| 1 | M | 61 | 2.4 (56) | 3.3 (67) | RL | 1.14 | 1.56 |
| 2 | M | 71 | 2.0 (43) | 2.8 (65) | LL | 1.05 | 1.47 |
| 3 | F | 58 | 2.8 (77) | 3.8 (91) | LL | 1.47 | 2.00 |
| 4 | M | 52 | 3.1 (74) | 4.3 (102) | LL | 1.63 | 2.26 |
| 5 | M | 66 | 1.9 (32) | 2.7 (50) | RL | 0.90 | 1.28 |
| 6 | M | 47 | 2.9 (64) | 4.0 (88) | RL | 1.44 | 1.98 |
| 7 | M | 78 | 2.1 (65) | 3.1 (82) | LL | 1.11 | 1.63 |
| Mean | | 61.9 | 2.46 (58.7) | 3.43 (77.9) | | 1.25 | 1.74 |
| ±SEM | | ±4.1 | ±0.2 (6.2) | ±0.2 (6.8) | | ±0.1 | ±0.1 |
| Lobectomy | | | | | | | |
| 1 | F | 55 | 3.0 (81) | 4.2 (99) | RUL + RML | 1.90 | 2.65 |
| 2 | M | 59 | 2.8 (74) | 3.8 (91) | LLL | 2.06 | 2.80 |
| 3 | M | 76 | 2.0 (52) | 2.7 (69) | LLL | 1.47 | 1.99 |
| 4 | M | 71 | 1.8 (39) | 2.7 (62) | RUL | 1.51 | 2.27 |
| 5 | F | 54 | 2.6 (79) | 3.8 (91) | RML + RLL | 1.64 | 2.40 |
| 6 | M | 60 | 1.4 (27) | 2.0 (31) | RLL | 1.03 | 1.47 |
| 7 | M | 42 | 3.2 (87) | 4.6 (101) | LLL | 2.36 | 3.39 |
| 8 | M | 57 | 2.9 (68) | 3.8 (82) | RUL | 2.44 | 3.20 |
| 9 | F | 61 | 2.3 (76) | 3.1 (90) | RUL + RML | 1.70 | 2.28 |
| 10 | M | 49 | 2.7 (68) | 3.6 (84) | RLL | 1.99 | 2.65 |
| Mean | | 58.4 | 2.47 (65.1) | 3.43 (80.0) | | 1.81 | 2.51 |
| ±SEM | | ±3.4 | ±0.2 (6.2) | ±0.3 (6.7) | | ±0.1 | ±0.2 |
| | | | | **Group B** | | | |
| Pneumonectomy | | | | | | | |
| 1 | M | 80 | 2.6 (61) | 3.4 (78) | LL | 1.35 | 1.78 |
| 2 | M | 61 | 2.1 (56) | 3.0 (70) | RL | 1.02 | 1.41 |
| 3 | F | 66 | 2.5 (82) | 3.4 (94) | LL | 1.34 | 1.80 |
| 4 | M | 59 | 2.9 (70) | 4.0 (91) | LL | 1.54 | 2.11 |
| Mean | | 66.5 | 2.55 (67.2) | 3.44 (83.2) | | 1.31 | 1.78 |
| ±SEM | | ±4.7 | ±0.2 (5.7) | ±0.2 (5.6) | | ±0.1 | ±0.1 |
| Lobectomy | | | | | | | |
| 1 | M | 61 | 2.4 (62) | 3.4 (77) | LUL | 1.93 | 2.71 |
| 2 | M | 64 | 1.7 (36) | 2.4 (55) | LLL | 1.24 | 1.77 |
| 3 | M | 63 | 1.8 (44) | 2.3 (50) | RUL + RML | 1.33 | 1.73 |
| 4 | F | 76 | 1.6 (51) | 1.9 (63) | RUL | 1.38 | 1.64 |
| 5 | F | 46 | 3.0 (88) | 3.9 (96) | LUL | 2.34 | 3.09 |
| 6 | F | 75 | 1.1 (49) | 1.7 (60) | RUL + RML | 0.83 | 1.28 |
| 7 | M | 60 | 1.6 (41) | 2.6 (61) | RUL | 1.38 | 2.25 |
| 8 | M | 63 | 2.5 (63) | 3.1 (72) | LLL | 1.83 | 2.26 |
| 9 | F | 51 | 2.5 (72) | 3.5 (91) | RUL | 2.01 | 2.95 |
| 10 | M | 66 | 2.1 (61) | 3.2 (80) | LUL | 1.67 | 2.56 |
| 11 | M | 59 | 1.8 (48) | 2.6 (61) | RLL | 1.35 | 1.95 |
| Mean | | 62.2 | 2.02 (55.9) | 2.81 (69.6) | | 1.57 | 2.20 |
| ±SEM | | ±2.7 | ±0.2 (4.6) | ±0.2 (4.5) | | ±0.1 | ±0.2 |

*M,* male; *RL,* right lung; *LL,* left lung; *F,* female; *SEM,* standard error of the mean; *RUL,* right upper lobe; *RML,* right middle lobe; *LLL,* left lower lobe; *LUL,* left upper lobe; *RLL,* right lower lobe.

*Values in liters (percent of predicted).

†Values in liters.

(64.6 ± 3.1 and 63.7 ± 2.9 cm $H_2O$, 2 weeks before the operation and just before the operation, respectively) and decreased significantly (to 59.6 ± 3.4 cm $H_2O$, $p = 0.04$) 3 months after the operation.

We found a good correlation between the actual and the predicted postoperative lung function values in the patients who did not receive IS and SIMT (group B) who underwent lobectomy ($r = -0.93$) or pneumonectomy ($r = -0.94$). The mean (plus or minus the standard error of the mean) actual postoperative $FEV_1$ was 1.38 ± 0.1 L for the patients who underwent pneumonectomy and 1.68 ± 0.1 for the patients who underwent lobectomy. The predicted postoperative $FEV_1$ value in these two groups underestimated the actual postoperative $FEV_1$ by 70 and 110 ml, respectively (Fig. 2). The mean postoperative FVC values were 2.28 ± 0.2 L for the patients who underwent lobectomy and 1.89 ± 0.1 L for the patients who underwent pneumonectomy. Again, the predicted postoperative FVC values in these two groups underestimated the actual postoperative FVC by 80 and 110 ml, respectively.

We also found a good correlation between the actual and the predicted postoperative lung function values in the patients who had received IS and SIMT (group A), whether they underwent lobectomy ($r = -0.97$) or pneumonectomy ($r = -0.88$). However, the mean actual postoperative $FEV_1$ was 1.93 ± 0.1 L for the patients who underwent pneumonectomy and 2.38 ± 0.1 L for the patients who underwent lobectomy. These postoperative $FEV_1$ values were higher than the predicted postoperative $FEV_1$ values by 680 and 570 ml, respectively (Fig. 3). The differences in postoperative $FEV_1$ values between the training group (group A) and the control group (group B) for both patients who underwent lobectomy and those who underwent pneumonectomy were statistically significant ($p = 0.001$). The mean postoperative FVC values were 3.16 ± 0.3 L for the patients who underwent lobectomy and 2.56 ± 0.1 L for the patients who underwent pneumonectomy. Again, the predicted postoperative FVC values underestimated the actual postoperative FVC values by 650 and 820 ml, respectively. The differences in postoperative FVC values between the training group (group A) and the control group (group B) for both patients who underwent lobectomy and those who underwent pneumonectomy were statistically significant ($p = 0.001$).

There were only a few complications in each group. Three patients in group A and 4 patients in group B needed mechanical ventilation for more than 24 hours after operation and two patients in each group had pneumonia after the operation. There was no mortality in either group.

## Discussion

The results of the present study indicate that the simple calculation of predicted postoperative lung function values, with the use of the formula as was described by Juhl and Frost,[5] correlates well with the actual postoperative lung function result, although it underestimates it by a small fraction. In addition, there is an indication that SIMT and IS, done before and after the operation, may improve postoperative lung function significantly.

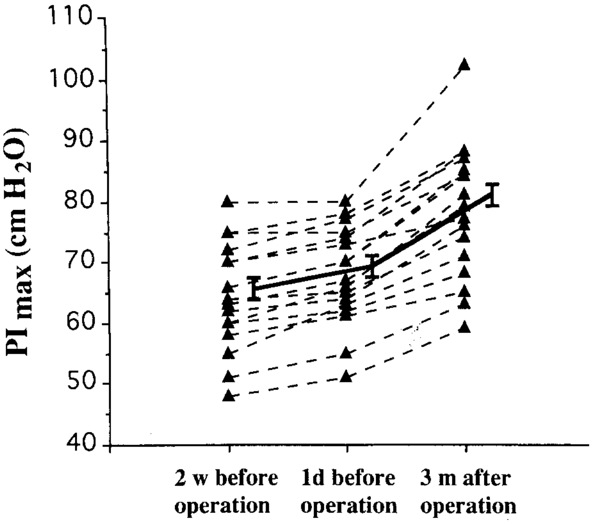

**Fig. 1.** Inspiratory muscle strength in the training group (group A) as expressed by the $PI_{max}$ at residual volume, at baseline, after 2 weeks of training but before operation, and after 3 months of training after lung resection.

Grossly impaired postoperative lung function is associated with high morbidity and mortality rates.[3, 12, 13] The criterion for operability for pneumonectomy of a predicted postoperative $FEV_1$ greater than 0.8 L or greater than 40% of predicted, as was suggested by these researchers, is still frequently used for defining operability. Although lung resection offers the best chance for cure in patients with nonmetastatic bronchogenic carcinoma,[14] the frequent coexistence of COPD increases the risk of operation because of impaired postoperative ventilatory function in such patients.[1, 2]

General prophylactic measures, such as smoking cessation, administration of antibiotics and bronchodilators, and chest physical therapy, have been shown to decrease the rate of complications in patients at high risk.[15] However, in patients undergoing lung resection the removal of lung tissue may grossly impair postoperative ventilatory function despite these measures.

Any maneuver that emphasizes inflation will increase lung volume and maintain patency of the smaller airways.[16] IS is the most widely prescribed technique for preoperative and postoperative lung expansion.[17] In addition, IS is characterized by active recruitment of the diaphragm and other in-

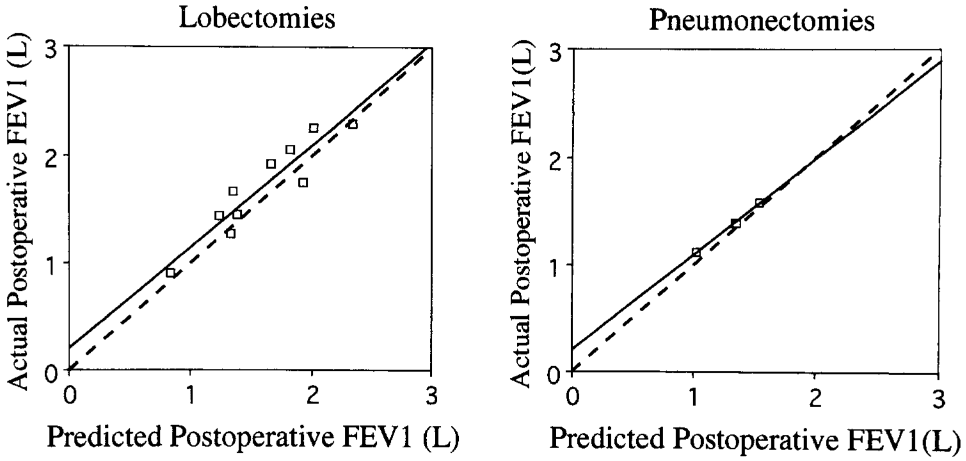

**Fig. 2.** The relationship between the predicted and the actual postoperative $FEV_1$ values in the patients undergoing lobectomy *(left graph)* and pneumonectomy *(right graph)* in the control group. The *solid line* represents the line of best fit by linear regression analysis, and the *hatched line* depicts the line of identity.

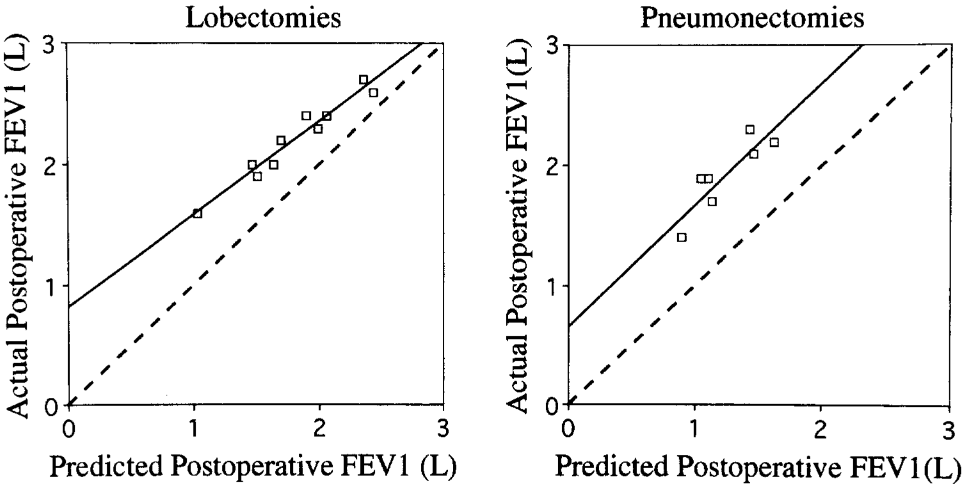

**Fig. 3.** The relationship between the predicted and the actual postoperative $FEV_1$ values in the patients undergoing lobectomy *(left graph)* and pneumonectomy *(right graph)* in the training group. The *solid line* represents the line of best fit by linear regression analysis, and the *hatched line* depicts the line of identity.

spiratory muscles. However, the efficacy of IS to enhance diaphragmatic excursion is still controversial.[18, 19]

In patients with COPD, hyperinflation of the lung places the inspiratory muscles at a mechanical disadvantage.[20] It has been shown that the inspiratory muscles of patients with COPD are weaker than those of normal persons.[21] In addition, after thoracotomy the mechanical efficiency of the respiratory system may be impaired as a result of pleural adhesions or distortion of the chest wall configuration.[22]

It has been established that respiratory muscles can be trained like other skeletal muscles, and several reviews have been published that deal with ventilatory muscle training.[23-25] It has also been observed that in patients with COPD the increased inspiratory muscle performance after SIMT is associated with improvement of lung function.[9]

Many studies have confirmed the value of the predicted postoperative $FEV_1$ in predicting mortality after lung resection.[3, 26] Although the precise tolerable lower limit of postoperative $FEV_1$ is hard to assess, values of postoperative $FEV_1$ greater than 800 ml or 40% of predicted are associated with almost no mortality, whereas values of postoperative

$FEV_1$ less than 800 ml or 40% of predicted are associated with high postoperative mortality. In this study we have demonstrated the value of simple calculation of predicted postoperative $FEV_1$ in the preoperative assessment of patients undergoing lung resection. We also found that inspiratory threshold loading training done 2 weeks before and 3 months after lung resection, added to IS, significantly improved inspiratory muscle strength in these patients. This improvement was associated with significantly better lung function test results as compared with those in the control group of patients who were not given training. In our patients, IS and SIMT were added to the administration of antibiotics and bronchodilators as prophylactic measures. Our group of patients did not have severe COPD, but IS and SIMT might be incorporated into pulmonary rehabilitation for patients with more severe conditions to decrease the rate of complications in high-risk groups. Thus with the use of IS and SIMT before and after operation, more patients may be candidates for potentially lifesaving lung resection.

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