JCS Journal of Chest Surgery
https://doi.org/10.5090/jcs.21.037
pISSN: 2765-1606 eISSN: 2765-1614
J Chest Surg. 2021;54(6):480-486

Clinical Research

# Changes in Forced Expiratory Volume in 1 Second after Anatomical Lung Resection according to the Number of Segments

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**ARTICLE INFO**
**Received** April 30, 2021
**Revised** September 5, 2021
**Accepted** September 13, 2021

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**Background:** Although various methods are already used to calculate predicted postoperative forced expiratory volume in 1 second ($FEV_1$) based on preoperative $FEV_1$ in lung surgery, the predicted postoperative $FEV_1$ is not always the same as the actual postoperative $FEV_1$. Observed postoperative $FEV_1$ values are usually the same or higher than the predicted postoperative $FEV_1$. To overcome this issue, we investigated the relationship between the number of resected lung segments and the discordance of preoperative and postoperative $FEV_1$ values.
**Methods:** From September 2014 to May 2020, the data of all patients who underwent anatomical lung resection by video-assisted thoracoscopic surgery (VATS) were gathered and analyzed retrospectively. We investigated the association between the number of resected segments and the differential $FEV_1$ (a measure of the discrepancy between the predicted and observed postoperative $FEV_1$) using the t-test and linear regression.
**Results:** Information on 238 patients who underwent VATS anatomical lung resection at Kyung Hee University Hospital at Gangdong and by DH. Kim for benign and malignant disease was collected. After applying the exclusion criteria, 114 patients were included in the final analysis. In the multiple linear regression model, the number of resected segments showed a positive correlation with the differential $FEV_1$ (Pearson r=0.384, p<0.001). After adjusting for multiple covariates, the differential $FEV_1$ increased by 0.048 (95% confidence interval, 0.023–0.073) with an increasing number of resected lung segments ($R^2$=0.271, p<0.001).
**Conclusion:** In this study, after pulmonary resection, the number of resected segments showed a positive correlation with the differential $FEV_1$.

**Keywords:** Video-assisted thoracoscopic surgery, Segmentectomy, Lobectomy, Respiratory function tests

## Introduction

Anatomical lung resection procedures, such as segmentectomy and lobectomy, have been performed for the surgical treatment of both malignant and benign lung diseases. The number of segments that will be resected during the procedure can be calculated. Counting the number of resected segments is 1 of many methods to calculate predicted postoperative forced expiratory volume in 1 second ($ppoFEV_1$) to assess a patient's operability [1,2]. However, the observed postoperative $FEV_1$ ($poFEV_1$) is not always the same as the $ppoFEV_1$ [1,3]. Usually, $poFEV_1$ is same or higher than $ppoFEV_1$, and there have been attempts to elucidate the reasons for this difference. Investigators have suggested that hyperinflation of the alveolar septal tissue of the residual lung, accompanied by compensatory lung growth, is the key mechanism underlying this difference [4-7]. However, the $poFEV_1$ is also sometimes lower than the $ppoFEV_1$. Predicting the extent of discordance is still an imperfect process, but the articles published so far imply that the discordance is related to the resected volume. In this study, the relationship between the number of resected segments and the discordance of $FEV_1$ was investigated, and other factors that could affect this discordance were identified.

# Methods

## Study design

This retrospective analysis was approved by the Institutional Review Board (IRB) of Kyung Hee University Hospital at Gangdong (IRB approval no., 2021-02-023). Data on 238 patients who underwent anatomical resection by video-assisted thoracoscopic surgery by a single surgeon between September 2014 and May 2020 were collected from the Kyung Hee University Hospital at Gangdong. The data included preoperative pulmonary function tests (PFTs), 6-month-postoperative PFTs [7,8], age, sex, height, weight, body mass index (BMI), number of resected segments, operation time, the presence of pulmonary ligament release, fixation between segments to avoid torsion, location of the operation, the maneuver for division of the segmental plane and fissural plane, smoking, comorbidities, and complications.

## Measuring discordance

We defined the discordance of $FEV_1$ postoperatively as the differential $FEV_1$ ($difFEV_1$), which was calculated as follows: $difFEV_1=(poFEV_1-ppoFEV_1)/ppoFEV_1$. We used the 6-month postoperative $FEV_1$ as $poFEV_1$, and the $ppoFEV_1$ was calculated as follows: $ppoFEV_1$=preoperative $FEV_1(19-n)/19$, where n stands for the number of resected segments, and 19 stands for the total number of lung segments.

## Exclusion criteria for this study

Among the 238 patients, we excluded those who did not receive a 6-month postoperative PFT (n=54), had a history of chemotherapy or radiation therapy (n=69), had previous lung surgery (n=8), pneumonectomy (n=1), anatomical resection with non-anatomical resection (n=11), or bilobectomy (n=1). Bronchoplastic procedures, such as bronchoplasty or sleeve lobectomy, can also affect pulmonary function, as stenosis of the anastomosis site may occur. However, according to the literature, pulmonary function after bronchoplastic procedures is comparable to that after standard lobectomy. Therefore, bronchoplasty and sleeve lobectomy were not classified as exclusion criteria [9,10]. Induction chemoradiotherapy can cause a reduction in preoperative pulmonary function [11,12]. Some investigators have proposed that the toxic effects of the treatment probably impair the postoperative recovery of lung parenchyma and interstitium [13,14]. However, other investigators have reported that adjuvant chemotherapy does not seem to reduce pulmonary function parameters [15]. For this study it was decided to include a history of chemoradiotherapy in the exclusion criteria, although the exact mechanisms and disturbance of pulmonary function are unclear. We excluded pneumonectomy and bilobectomy, although they are also anatomical resections, because their numbers were too small for statistical analysis (Fig. 1). After applying the exclusion criteria described above, 114 patients were enrolled in the study.

## Pulmonary function test

$FEV_1$ was measured using a dry rolling-seal spirometer (VMAX 22 Body Box; Sensor Medics Italia, Milan, Italy).

## Statistical analysis

Information on the 114 final study participants was collected by a retrospective chart review. The baseline characteristics of the study participants were expressed as the mean±standard deviation for continuous variables and number (%) for categorical variables. A simple linear regression model was used to show the correlation between the number of resected segments and $difFEV_1$. Finally, a multiple linear regression model was used to determine the

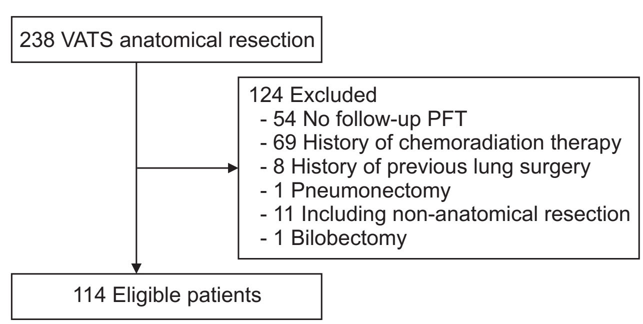


**Fig. 1.** Flowchart of the study. Pneumonectomy and bilobectomy were excluded because obtaining statistically meaningful results were not possible though they are also anatomical resections. Several patients were duplicated in the exclusion group because of overlap in the reasons for exclusion. VATS, video-assisted thoracoscopic surgery; PFT, pulmonary function test.

https://doi.org/10.5090/jcs.21.037

significant predictive variables for difFEV$_1$. In the multiple linear regression model, age (years), BMI (kg/m$^2$), number of resected segments, sex (female versus male), smoking (smokers versus non-smokers), fixation to avoid torsion (yes versus no), pulmonary ligament release (yes versus no), location, and usage of stapler were included as predictors for difFEV$_1$. Multicollinearity and basic assumptions were checked for the linear regression model, and there was no multicollinearity problem or violation of the basic assumption. Statistical significance was set at $p<0.05$. The R ver. 4.0 (The R Foundation for Statistical Computing, Vienna, Austria; https://www.r-project.org) and Jamovi ver. 1.2.27 (The Jamovi Project, Sydney, Australia; https://www.jamovi.org) were used as statistical software programs.

**Table 1.** Baseline characteristics of 114 patients who underwent anatomical lung resection by video-assisted thoracoscopic surgery

| Characteristic | Value (n=114) |
|---|---|
| Age (yr) | 65.78±9.25 |
| Sex | |
| Male | 65 (57) |
| Female | 49 (43) |
| Height (cm) | 161.23±8.63 |
| Weight (kg) | 63.11±11.07 |
| Body mass index (kg/m$^2$) | 24.20±3.28 |
| Disease type | |
| Malignant disease | 104 (91) |
| Benign disease | 10 (9) |
| Smoking | 59 (52) |
| Asthma | 13 (11) |
| Chronic obstructive pulmonary disease | 49 (43) |
| Location of resection | |
| Right upper lobe | 38 (33) |
| Right middle lobe | 9 (8) |
| Right lower lobe | 22 (19) |
| Left upper lobe | 26 (23) |
| Left lower lobe | 19 (17) |
| Operation time (min) | 200±55.45 |
| Pulmonary ligament release | 76 (67) |
| Fixation to avoid torsion | 10 (9) |
| Operation type | |
| Segmentectomy | 47 (41) |
| Lobectomy | 67 (59) |
| Resected segments | |
| 1 | 18 (16) |
| 2 | 25 (22) |
| 3 | 32 (28) |
| 4 | 17 (15) |
| 5 | 22 (19) |
| Preoperative FEV$_1$ (L) | 2.33±0.66 |

Values are presented as mean±standard deviation or number (%).
FEV$_1$, forced expiratory volume in 1 second.

## Results

Among the 238 patients considered, 124 were excluded and 114 patients were included; their characteristics are summarized in Table 1. The mean age was 65.78 years, and 65 (57%) were male. The mean BMI was 24.20 kg/m$^2$, which is within the mean range provided by the World Health Organization, but toward the upper end of normal. A total of 104 patients (91%) had malignant diseases. Fifty-nine (52%), 13 (11%), and 49 (43%) patients had a history of smoking, asthma, and chronic obstructive pulmonary disease, respectively. The distribution across the various locations was as follows: right upper lobe in 38 patients (33%), right middle lobe in 9 (8%), right lower lobe in 22 (19%), left upper lobe in 26 (23%), and left lower lobe in 19 (17%). The mean operation time was 200 minutes, but it violated the assumption of equal variances (Levene test; $p<0.008$). Pulmonary ligament release was performed in 76 patients (67%). Fixation between segments to avoid torsion was performed in 10 patients (9%). Segmentectomy was performed in 47 patients (41%). The distribution of the number of resected segments was as follows: 1 segment in 18 patients (16%), 2 segments in 25 patients (22%), 3 segments in 32 patients (28%), 4 segments in 17 patients (15%), and 5 segments in 22 patients (19%). The mean preoperative FEV$_1$ was 2.33.

Table 2 and Fig. 2 show the relationship between the number of resected segments and difFEV$_1$. Table 2 shows the changes in difFEV$_1$ with the number of resected segments. In the group with 1 resected segment, difFEV$_1$ was -0.04±0.09. This means that there was no meaningful difference between ppoFEV$_1$ and poFEV$_1$ if only 1 segment was resected during the procedure. However, for the group with 2 resected segments, difFEV$_1$ was 0.12±0.13. The discordance seemed to markedly increase from the 1-segment-resection to 2-segment-resection groups, favoring poFEV$_1$. As the number of resected segments increased

**Table 2.** Changes in difFEV$_1$ with the number of resected lung segments

| No. of resected segments | difFEV$_1$ |
|---|---|
| 1 | -0.04±0.09 |
| 2 | 0.12±0.13 |
| 3 | 0.04±0.15 |
| 4 | 0.13±0.10 |
| 5 | 0.17±0.16 |

Values are presented as mean±standard deviation.
FEV$_1$, forced expiratory volume in 1 second; difFEV$_1$, the postoperative discordance of FEV$_1$.

from 3 to 5, $difFEV_1$ gradually increased to 0.04±0.15, 0.13±0.10, and 0.17±0.16, respectively. Fig. 2 shows the linear relationship between the number of resected segments and $difFEV_1$. There was a significant positive linear relationship between the number of resected segments and $difFEV_1$ (Pearson r=0.384, p<0.001).

After adjusting for age, sex, smoking status, BMI, pulmonary ligament release, fixation to avoid torsion, location of operation, and the maneuver for division of the segmental plane and fissural plane, in the multiple linear regression model, the $difFEV_1$ increased significantly by 0.048 (95% confidence interval [CI], 0.023–0.073) as the number of resected segments increased ($R^2$=0.271, p<0.001). These findings show that the discordance in $FEV_1$ was significantly affected by the number of resected segments, independent of age, sex, smoking status, location, and BMI (Table 3).

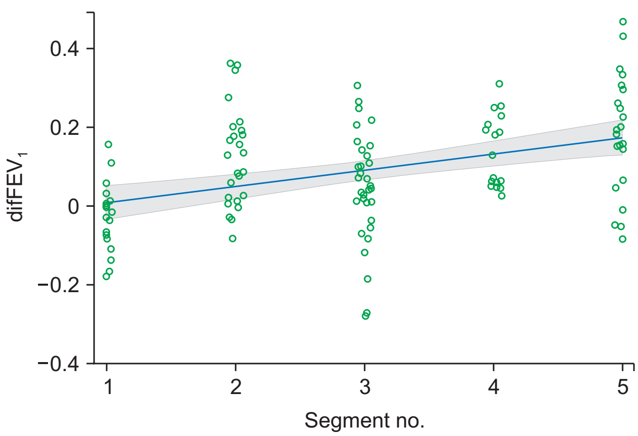


**Fig. 2.** Multiple linear regression analyses showing the correlation between the number of resected segments and $difFEV_1$ (the postoperative discordance of forced expiratory volume in 1 second). The distribution was expressed as dots. The dark gray band shows the 95% confidence interval.

## Discussion

In anatomical resection, although there are many methods to predict $ppoFEV_1$ using anatomical information, there are differences between the actual $poFEV_1$ and $ppoFEV_1$, and many studies have shown that $ppoFEV_1$ is not equal to $poFEV_1$. The aim of this study was to explain the discordance between $poFEV_1$ and $ppoFEV_1$ using information that can be easily obtained by practitioners, and thus help them to determine the best treatment for their patients. Many investigators have tried to elucidate the reasons for the difference between $poFEV_1$ and $ppoFEV_1$, and we hypothesized that the empty space created by the resected volume of the lung during the procedure may be a significant factor. Thus, we designed a study to investigate the relationship between the number of resected segments and the discordance in $FEV_1$.

In the group with 1 resected segment, $difFEV_1$ was -0.04±0.09, which can be interpreted as no significant discordance. We believe that the reasons for a median dif-

**Table 3.** Predictors of $difFEV_1$

| Predictor | Estimate | Standard error | p-value | 95% Confidence interval | t-value |
|---|---|---|---|---|---|
| Segment number | 0.048 | 0.012 | <0.001 | 0.023 to 0.073 | 3.880 |
| Pulmonary ligament release | | | | | |
| 0–1 | 0.062 | 0.034 | 0.068 | -0.005 to 0.129 | -1.846 |
| Fixation to avoid torsion | | | | | |
| 1–0 | -0.026 | 0.047 | 0.577 | -0.120 to 0.067 | -0.559 |
| Age (yr) | 0.002 | 0.001 | 0.26 | -0.001 to 0.004 | 1.134 |
| Sex | | | | | |
| Male (vs. female) | -0.039 | 0.039 | 0.327 | -0.116 to 0.039 | -0.985 |
| Smoking | | | | | |
| Smokers (vs. non-smokers) | -0.007 | 0.037 | 0.859 | -0.080 to 0.067 | -0.178 |
| Body mass index (kg/$m^2$) | 0.004 | 0.004 | 0.393 | -0.005 to 0.013 | 0.859 |
| Location | | | | | |
| LUL–LLL | 0.001 | 0.045 | 0.982 | -0.088 to 0.090 | 0.022 |
| RLL–LLL | -0.011 | 0.045 | 0.81 | -0.100 to 0.078 | -0.241 |
| RML–LLL | 0.032 | 0.062 | 0.61 | -0.092 to 0.156 | 0.511 |
| RUL–LLL | -0.057 | 0.043 | 0.183 | -0.141 to 0.027 | -1.339 |
| Stapler | | | | | |
| 1–0 | 0.009 | 0.032 | 0.781 | -0.055 to 0.073 | 0.279 |

$difFEV_1$, the postoperative discordance of $FEV_1$; LUL, left upper lobe; LLL, left lower lobe; RLL, right lower lobe; RML, right middle lobe; RUL, right upper lobe.

https://doi.org/10.5090/jcs.21.037

$FEV_1$ value of -0.04, even though the compensation mechanism was the same as in the other groups, are (1) the tendency to resect more parenchyma than the actual segmental plane to obtain a sufficient margin around the tumor, and (2) lung folding caused by division of the segmental plane using staplers [16,17]. These techniques are frequently performed by practitioners during 1-segment-resection segmentectomy. This practice may result in a negative mean value of $difFEV_1$ in the group with 1 resected segment, which cannot be compensated for by the positive effects on $difFEV_1$ caused by mechanisms that occur equally in the other groups showing positive $difFEV_1$ values. The results showed a linear correlation between the number of resected segments and the ratio of postoperative discordance in $FEV_1$. However, the group with 2 segments resected did not follow this trend. We believe that this deviation has a strong relationship with the anatomy of the 2-segment-resection group. Although there were 11 cases of 2-segment-resection of the right upper lobe, right lower lobe, left upper division, and left lower lobe, there were 14 cases of right middle lobectomy or left lingulectomy. The accessibility of these anatomical sites may induce good postoperative compensation due to less handling, less anatomical scarring on adjacent lung tissue, and less anatomical postoperative transformation compared with the other resection groups. However, it was not possible to obtain a statistically significant result because the number of patients was insufficient.

Although some authors recommend measuring only $FEV_1$ to evaluate lung function [18], additional methods such as the diffusion capacity of carbon dioxide [19] or $VO_2max$ [20] are also recommended for evaluating lung function, and we think these other values are also worth analyzing. Although these additional values were not included in our initial study due to a lack of data, we will investigate them if sufficient data are obtained in the future.

In our opinion, the major reasons for the correlation between the number of resected segments and the discordance ratio are as follows: (1) hyperinflation; (2) compensatory lung growth (i.e., if there is more space for hyperinflation or compensatory lung growth for the remnant lung, the remnant lung will grow more); and (3) defective lung volume (i.e., resection of larger segments often means a previously high defective lung volume, resulting from destruction, obstruction, or a mass effect from either benign or malignant disease). Therefore, lung compensation can be overestimated during the resection of large segments. To overcome this problem, 3-dimensional computed tomography image reconstruction or a perfusion scan can help to evaluate non-functional areas [21-23].

The effect of pulmonary ligament release on residual lung function is a controversial topic. Although releasing the pulmonary ligament can improve residual lung function by reducing dead space after lung surgery, it can also impair the residual lung function by inducing postoperative atelectasis. Release of the pulmonary ligament must be performed during lower lobe lobectomy, though it is not an essential procedure in other lobectomies. Preservation of the pulmonary ligament during the other lobectomies depends on the surgeon's preference. Although some investigators have reported that division of the inferior pulmonary ligament was not significantly correlated with postoperative $FEV_1$ [24], in this study, the division of the inferior pulmonary ligament was associated with a decrease in $difFEV_1$ by 0.062 (95% CI, -0.005 to 0.129) without statistical significance ($p=0.062$). Release of the inferior pulmonary ligament can help recover pulmonary function by filling the dead space. Conversely, kinking and obstruction of the bronchus induced by excessive relocation of a remnant lung after the release of the inferior pulmonary ligament can impair pulmonary function [25,26]. These results are from a single-center study with a small sample size. This limitation of our study can be overcome if the database is expanded or the study is reinforced by additional multicenter data.

Other predictors, such as division of the fissure or segmental plane using a stapler, fixation to avoid torsion, or location of resection, can also affect $difFEV_1$. An attempt to evaluate $difFEV_1$ according to whether the plane was maneuvered using a stapler through a subgroup analysis was unsuccessful because of the small sample size. However, multiple regression tests were performed, and the results were not statistically significant ($p=0.781$). In addition, an attempt was made to evaluate the correlation between fixation to avoid torsion and $difFEV_1$, but the results were not statistically significant ($p=0.577$). Investigation of other predictors will be attempted if the total number of patients necessary to enable statistical investigation becomes available.

We defined the postoperative discordance of $FEV_1$ as $difFEV_1$ because $difFEV_1$ can be used to predict a more accurate value of $poFEV_1$ by using the following formula: $poFEV_1=ppoFEV_1\times(1+difFEV_1)=preopFEV_1\times[(19-n)/19]\times(1+difFEV_1)$, where n is the number of resected segments. Although there are various methods to evaluate the patient's operability for lung surgery, according to the German Cancer Society, a $ppoFEV_1$ between 0.8–1.5 L means borderline operability. Based on our findings, if a patient requiring a 4-segment resection has an $FEV_1$ of 1.01 L, the $ppoFEV_1$ according to the original method is 0.797 L; however, if we consider the predicted $difFEV_1$, the $ppoFEV_1$ becomes 0.901 L and the operation becomes an option for that patient. In brief, the clinical implication of our study is that lung resection could be considered for more patients with impaired $FEV_1$. The $R^2$ value of our model is only 0.236; therefore, it cannot completely predict postoperative $FEV_1$, but it presents a statistically meaningful linear correlation between the discordance of $FEV_1$ and the number of resected segments. Moreover, we hope to develop a method of incorporating $difFEV_1$ into clinical decision-making so that patients can be better evaluated preoperatively and have a higher chance of curative therapy.

## Conflict of interest

No potential conflict of interest relevant to this article was reported.

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