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Lobe-Specific Variability in Postoperative Pulmonary Function in Lung Cancer Patients: A Longitudinal Analysis and Comparison With Traditional Predictive Models

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ABSTRACT

Background and Objective: Lobectomy is the primary treatment for early-stage non-small cell lung cancer. However, pulmonary function declines postoperatively, presenting a significant challenge. This study investigated pulmonary function following lobectomy and compared these changes with predicted lung function based on the traditional segmental method, focusing on resected lobe-specific variability.

Methods: This prospective cohort study included 419 patients who underwent lobectomies for NSCLC. Pulmonary function tests measuring forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and diffusion capacity for carbon monoxide (DLCO) were conducted preoperatively and at 1, 3, 6, and 12 months postoperatively. We compared the observed pulmonary function values to the predicted postoperative (PPO) values based on the traditional segmental method and analysed lobe-specific differences using mixed-effects models.

Results: Left upper and right lower lobectomies demonstrated observed pulmonary function values similar to their PPOs as early as 2 weeks postoperatively. However, the other lobes declined significantly, with an approximately 25% reduction in FVC, FEV1, and DLCO, regardless of the number of segments in the lobe. Three months postoperatively, observed pulmonary function values exceeded PPO values across all lobes. Surgical approach (open vs. video-assisted thoracoscopic surgery), right upper lobectomy in the reference to right lower lobectomy, and postoperative decreased physical activity were significant factors related to the non-recovery of lung function to their PPOs at 6 months after surgery.

Conclusion: Postoperative pulmonary function recovery varied significantly by resected lobe, with most lobes showing better recovery than predicted postoperative values. Accurate outcome prediction requires accounting for lobe-specific characteristics and compensatory mechanisms.

Joint first authorship: Yeong Jeong Jeon and Sumin Shin contributed equally to this research study.

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1 | Introduction

Lung cancer is the leading cause of cancer-related death worldwide [1]. Although lobectomy has traditionally served as the primary curative treatment for early-stage non-small cell lung cancer (NSCLC) [2, 3], recent phase 3 randomised studies [4, 5] demonstrated that, in well-selected patients with small and peripheral NSCLC, sublobar resections (segmentectomy or wedge resection) can achieve non-inferior overall survival while offering better preservation of postoperative pulmonary function than conventional lobectomy. Nonetheless, many patients still undergo lobectomy, and the resultant decline in pulmonary function continues to pose a significant challenge, affecting both quality of life and long-term health [6]. Theoretically, postoperative pulmonary function depends on the degree of resection [7, 8], however, the function can change over time after lobectomy, and predicted pulmonary function can differ from actual postoperative pulmonary function depending on the elapsed time [9, 10]. Understanding the time-dependent recovery of lung function after different types of lung resection can help optimise patient care and facilitate surgical decision-making.

Previous studies have examined the effects of lobectomy and pneumonectomy on postoperative lung function, focusing on measures such as forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and diffusion capacity for carbon monoxide (DLCO) [10]. The compensatory mechanisms of the remaining lung tissue are vital for reducing functional losses caused by resection. Previous papers showed that lower lobectomy leads to a smaller overall reduction in lung volume than upper lobectomy due to significant compensatory expansion in the opposite lung [11, 12]. This highlights the variability in lobe-specific postoperative outcomes.

Predicting postoperative FEV_1 and DLCO is essential for selecting patients for major lung resection. The 'anatomical method' is routinely used to calculate the predicted postoperative (PPO) FEV_1 and DLCO for patients undergoing lobectomy. According to the European Respiratory Society and European Society of Thoracic Surgery guidelines, these PPO values help estimate the risk of death and cardiopulmonary complications after resection. Predicting these values preoperatively helps to identify patients at higher risk for postoperative complications and customise perioperative care accordingly. However, the "anatomical method" does not account for the specific location of the lobe, and it is unclear whether estimated PPO accurately reflects actual lung function. Thus, our study investigated pulmonary function, specifically FVC, FEV_1, and DLCO, over time following lung resection, focusing on lobe-specific differences. Using a longitudinal approach, we aimed to identify lung function and physiological recovery patterns by resected lobe.

2 | Methods

2.1 | Study Design and Participants

We used data from a prospective cohort study called the Coordinated Approach to Cancer Patients' Health for Lung Cancer (CATCH-LUNG), which recruited patients who were expected to undergo curative lung cancer surgery for suspected NSCLC at the Samsung Medical Center in Seoul, Korea, between March 2016 and October 2018. The inclusion criteria were as follows: (1) expected to undergo curative lung cancer surgery for suspected or histologically confirmed NSCLC, (2) Eastern Cooperative Oncology Group performance status of either 0 or 1, (3) no problems walking, and (4) understood the purpose of the study and agreed to participate [13]. Among the patients included in the CATCH-LUNG cohort, the analysis was restricted to those who underwent curative lobectomy and were ultimately diagnosed with stages I–III lung cancer postoperatively ($n = 646$). To evaluate the impact of surgery, we excluded patients who underwent simultaneous lung resection ($n = 80$) or who received adjuvant treatment after surgery ($n = 174$). In addition, because our study aimed to determine lung function recovery at 1, 3, 6, and 12 months after surgery, we excluded patients with incomplete follow-up ($n = 3$). Finally, 419 patients were included. The study protocol was approved by the Institutional Review Board of the Samsung Medical Center (IRB no. 2015-11-025). Written informed consent was obtained from all participants.

2.2 | Measurements

Pulmonary function tests were performed before surgery and were repeated at 2 weeks and 3, 6, and 12 months after surgery. To test pulmonary function, spirometry was performed using a Vmax 22 (SensorMedics, OH, USA) according to the American Thoracic Society/European Respiratory Society criteria [14, 15]. Absolute values of FEV_1, FVC, and DLCO were obtained, and the percentages of the predicted values (% predicted) for FEV_1, FVC, and DLCO were calculated using a reference equation based on a representative Korean sample [16, 17]. PPO pulmonary function after lobectomy was calculated as previously described [18]. The PPO-FEV_1, PPO-FVC, and PPO-DLCO values were calculated based on preoperative values, the number of functional lung segments resected, and the total number of functional segments available at resection. The total number of segments for both lungs was 19:10 in the right lung (3 upper, 2 middle, and 5 lower lobes) and 9 in the left lung (5 upper and 4 lower lobes) [18].

Patient information, including age, sex, comorbidities, and smoking status, was obtained preoperatively using standard questionnaires. Clinical data, including surgical approach, pathological type, pathological stage, and adjuvant treatment, was collected from electronic medical records after surgery. Chronic obstructive pulmonary disease was defined as a post-bronchodilator (BD) FEV_1/FVC ratio of < 0.7. Postoperative pulmonary complications were prospectively recorded according to previously established definitions [13, 19]. Physical activity was assessed using a reliable wearable activity tracker [20]. The tracker Flex (FITBIT, USA) was used to count steps and classify the intensity and time of the physical activity as moderate or vigorous (MVPA). MVPA is defined as physical activity performed at an intensity of more than 3 metabolic equivalents (METs). The activity data were collected as previously described [21]. Low physical activity was defined as less than 30 min per day of MVPA based on the recommendations of the World Health Organization (at least 150 min/week MVPA) [22] or a decrease in daily steps by increments of 1000 steps compared with other patients [23, 24].

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2.3 | Statistical Analysis

Descriptive statistics were used to summarise the patient characteristics. We used mixed-effects models for longitudinal data analysis to model changes in the absolute FVC, FEV_1, and DLCO values and the percentages of predicted values (% predicted) for FEV_1, FVC, and DLCO at each time point. These mixed models provided the average longitudinal change from preoperative values (with 95% confidence intervals [CIs]) while allowing for random variations in longitudinal changes among participants according to normal distributions with unstructured variance–covariance matrices. In addition, we compared the difference in lobe-specific changes in pulmonary function from the preoperative values using a mixed model that included interaction terms between time and resection lobe. We also calculated the difference between PPO pulmonary function and observed pulmonary function to assess how this discrepancy changed over time in the resected lobe.

To identify the factors associated with failure to reach PPO pulmonary function, the group was divided into two categories: non-recovered and recovered. Recovery was defined as lung function above the PPO value at the 6-month follow-up.

We then used a logistic regression model to calculate the odds ratios (ORs) and 95% CIs for the differences in the odds of non-recovery for the factors at baseline and those that changed at baseline and at 2 weeks after surgery. To further evaluate the relationship between PPO pulmonary function and early surgical outcomes, we performed logistic regression analyses of 30-day postoperative complications using PPO-FEV_1, PPO-FVC, and PPO-DLCO as continuous predictors.

Significance was set at a p value <0.05. All analyses were performed using R version 4.1.3 (R Foundation for Statistical Computing, Vienna, Austria).

3 | Results

3.1 | Patients

The mean (SD) age of the study participants was 62.3 (9.2), and 51.3% ($n=215$) were male. Among the participants, 88.1% were diagnosed with adenocarcinoma, 94.7% were diagnosed with stage I disease, and almost 90% underwent video-assisted thoracoscopic surgery (VATS) (Table 1). Among the 419 patients, 59, 90, 90, 29, and 151 underwent lobectomies for left lower lobe (LLL), left upper lobe (LUL), right lower lobe (RLL), right middle lobe (RML), and right upper lobe (RUL), respectively.

3.2 | Changes in Pulmonary Function

The preoperative average (standard deviation [SD]) FVC, FVC (% predicted), FEV_1, FEV_1 (% predicted), DLCO, and DLCO (% predicted) values are presented in Table S1. The pulmonary function was similar in patients who underwent lobectomy for the LLL, LUL, RLL, RML, and RUL at baseline, except for DLCO (% predicted). The lower lobes (LLL and RLL) had a relatively lower DLCO (% predicted) than the middle or upper lobes (LUL, RML, or RUL) (Table S1).

The mean observed FVC and FVC (% predicted) was decreased 2 weeks after surgery, then increased but remained below baseline at 12 months (Table S1, Figure 1A,B). Patients who underwent right middle lobectomy had the smallest decrease in FVC (−641.2 mL at 2 weeks after surgery, −88.1 mL at 12 months after surgery), whereas those with right lower lobectomy had the largest decrease in FVC (−949.5 mL at 2 weeks after surgery, −399.6 mL at 12 months after surgery; Table S2, Figure 1).

3.3 | Discrepancy in Observed vs. PPO Pulmonary Function

Figure 2 and Table S3 present a comparison of the observed and PPO pulmonary functions (traditional segmental method predicted) at various time points after lobectomy. For FVC, both absolute values and percentages of predicted values, right upper lobectomy showed the largest initial decrease below PPO level at 2 weeks (−295.3 mL and −7.7%), with gradual improvements above PPO level to 140.3 mL and 3.9% at 3 months, 279.2 mL and 7.5% at 6 months, and 296.3 mL and 8.2% at 12 months after surgery. In contrast, the left upper lobectomy showed the smallest decrease below PPO level in FVC at 2 weeks (−2.1 mL, 0.7%) and progressively greater increases above PPO level, reaching 402.9 mL and 11.6% at 3 months, 500.0 mL and 14.2% at 6 months, and 509.2 mL and 15.8% at 12 months after surgery.

Regarding FEV_1, the right upper lobectomy had the largest initial decrease below PPO level at 2 weeks (−226.0 mL and −8.0%), with partial recoveries above PPO levels to 74.5 mL and 2.9% at 3 months, 128.0 mL and 4.8% at 6 months, and 122.5 mL and 5.3% at 12 months after surgery. Conversely, the right lower lobectomy showed observed FEV1 level above PPO level at 2 weeks (30.7 mL and 1.5%), improving further to 337.1 mL and 12.1% at 3 months, 418.6 mL and 14.5% at 6 months, and 398.8 mL and 15.1% at 12 months after surgery.

For DLCO, both in terms of absolute values and percentages of predicted values, right lower lobectomy showed the largest initial decrease below PPO level at 2 weeks (−4.1 mL/min/mmHg and −22.7%), with partial recoveries above PPO level to 1.9 mL/min/mmHg and 8.8% at 3 months, 1.9 mL/min/mmHg and 10.3% at 6 months, and 2.3 mL/min/mmHg and 13.1% at 12 months after surgery. Conversely, left lower lobectomy showed an observed DLCO level above PPO level even at 2 weeks (7.1 mL/min/mmHg and 28.0%) and maintained smaller increases above PPO level with 0.8 mL/min/mmHg and 4.7% at 3 months, 0.6 mL/min/mmHg and 4.2% at 6 months, and 0.6 mL/min/mmHg and 5.0% at 12 months after surgery.

3.4 | Factors Associated With Failure to Reach PPO Pulmonary Function at 6 Months After Surgery

Based on the observed pulmonary function, the proportions of patients who did not reach PPO-FVC (% predicted), FEV_1

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TABLE 1 | Clinical and surgical characteristics of participants.

Characteristic	Overall ($N=419$)	Location of lobectomy					
		LLL ($n=59$)	LUL ($n=90$)	RLL ($n=90$)	RML ($n=29$)	RUL ($n=151$)	p
Age, years, mean (SD)	62.3 (9.2)	60.9 (9.6)	64.2 (8.4)	61.4 (9.4)	61.8 (9.3)	62.3 (9.2)	0.201
Sex (men, %)	215 (51.3)	27 (45.8)	50 (55.6)	41 (45.6)	13 (44.8)	84 (55.6)	0.382
BMI, kg/m^2 mean (SD)	23.94 (2.9)	23.65(2.7)	24.23 (2.8)	23.96 (2.9)	24.44 (2.6)	23.77 (3.0)	0.574
Smoking status (ever, %)	196 (46.8)	25 (42.4)	47 (52.2)	38 (42.2)	13 (44.8)	73 (48.3)	0.649
Comorbidities							
COPD	87 (20.8)	9 (15.3)	29 (32.2)	13 (14.4)	3 (10.3)	33 (21.9)	0.014
Hypertension	154 (36.8)	17 (28.8)	40 (44.4)	31 (34.4)	10 (34.5)	56 (37.1)	0.384
Diabetes mellitus	59 (14.1)	7 (11.9)	21 (23.3)	9 (10.0)	7 (24.1)	15 (9.9)	0.015
Cardiovascular disease	18 (4.3)	3 (5.1)	5 (5.6)	3 (3.3)	1 (3.4)	6 (4.0)	0.948
Cell type (Adenocarcinoma, %)	369 (88.1)	52 (88.1)	80 (88.9)	76 (84.4)	28 (96.6)	133 (88.1)	0.607
Pathologic stage							0.792
I	397 (94.7)	56 (94.9)	84 (93.3)	86 (95.6)	28 (96.6)	143 (94.7)	
II	16 (3.8)	3 (5.1)	3 (3.3)	4 (4.4)	1 (3.4)	5 (3.3)	
III	5 (1.2)	0 (0.0)	3 (3.3)	0 (0.0)	0 (0.0)	2 (1.3)	
IV	1 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.7)	
Steps	10238.58 (5471.46)	10456.67 (5116.82)	10522.91 (5253.32)	9354.48 (5522.29)	11426.13 (4314.23)	10281.40 (5891.39)	0.426
MVPA							
<30 min/day	146 (34.8)	21 (35.6)	31 (34.4)	34 (37.8)	6 (20.7)	54 (35.8)	0.800
≥ 30 min/day	247 (58.9)	33 (55.9)	54 (60.0)	51 (56.7)	22 (75.9)	87 (57.6)	
Surgical approach (VATS, %)	368 (87.8)	54 (91.5)	77 (85.6)	82 (91.1)	26 (89.7)	129 (85.4)	0.558

Note: The values in the table are the means ± standard deviations, or n (%).
Abbreviations: BMI, body mass index; COPD, chronic obstructive pulmonary disease; LLL, left lower lobe; LUL, left upper lobe; MVPA, moderate-to-vigorous physical activity; PPC, postoperative pulmonary complication; RLL, right lower lobe; RML, right middle lobe; RUL, right upper lobe; VATS, video-assisted thoracoscopic surgery.

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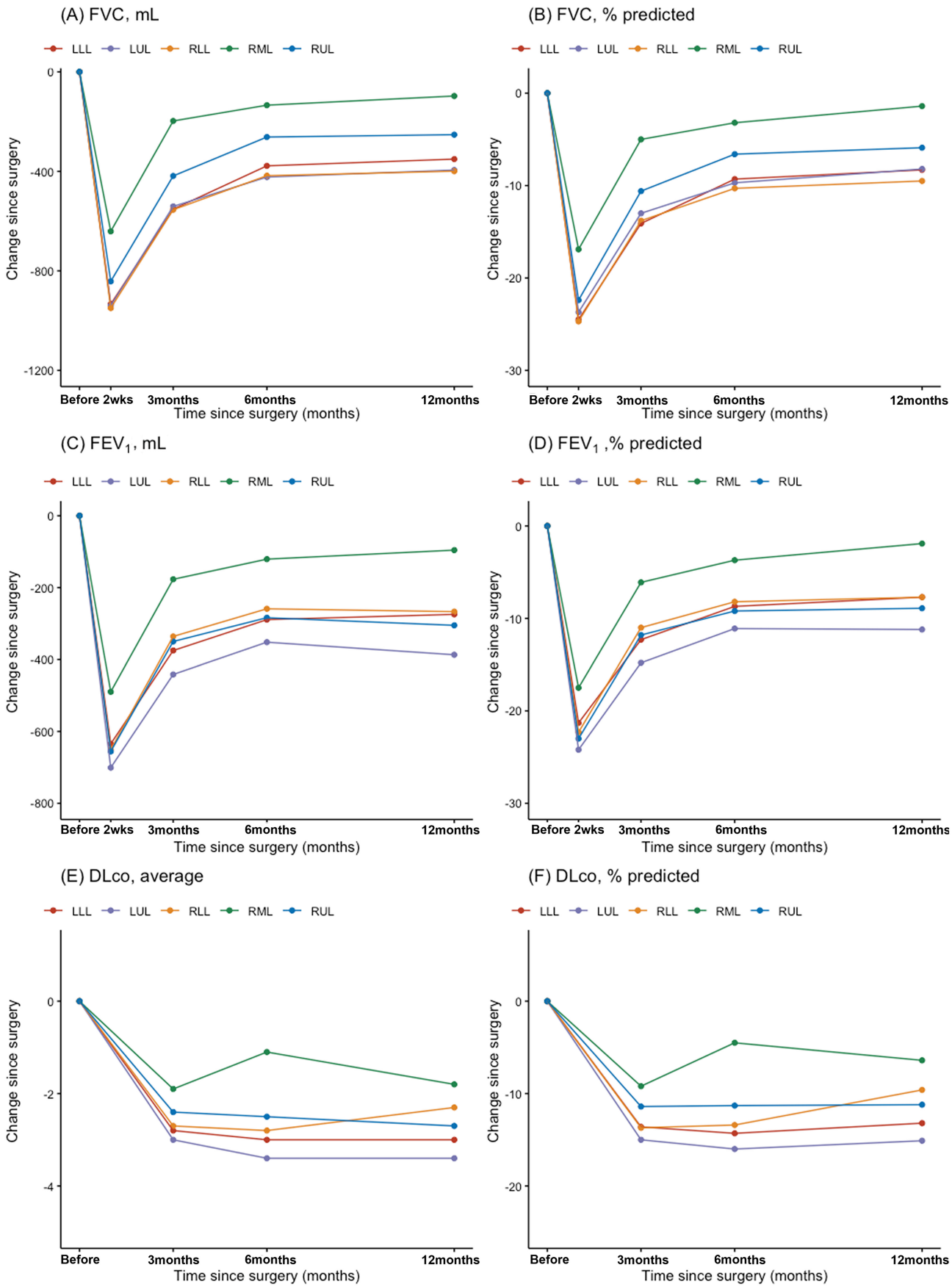


FIGURE 1 | Changes in pulmonary function from baseline to 2 weeks, 3, 6, and 12 months after surgery.

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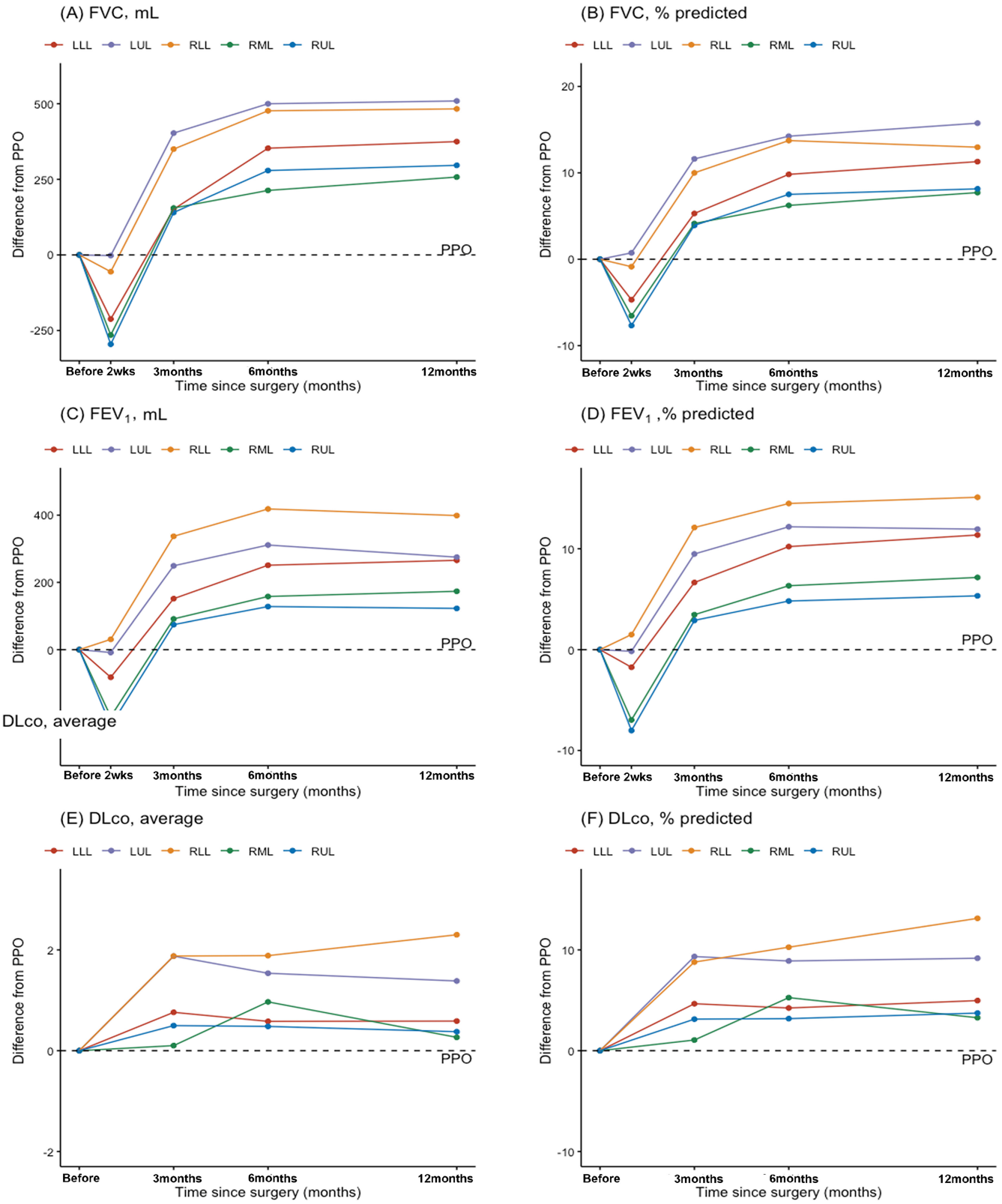


FIGURE 2 | Differences between changes and predicted postoperative pulmonary function from baseline to 2 weeks, 3, 6, and 12 months after surgery. LLL, left lower lobe; LUL, left upper lobe; RLL, right lower lobe; RML, right middle lobe; RUL, right upper lobe.

(% predicted), and DLCO (% predicted) at 6 months after surgery were 11.5%, 16.5%, and 27.7%, respectively (Figure 3). Among the resected lobes, right middle and upper lobectomies were most likely to have non-recovery of FVC (RML = 18.5%, RUL = 17.7%), FEV_1 (RML = 14.8%, RUL = 28.2%), or DLCO (RML = 29.6%, RUL = 35.5%) to PPO values at 6 months after surgery compared with the other lobes (Figure 3).

After adjusting for confounding factors, right upper lobectomy was associated with non-recovery of FEV1 (% predicted) (adjusted

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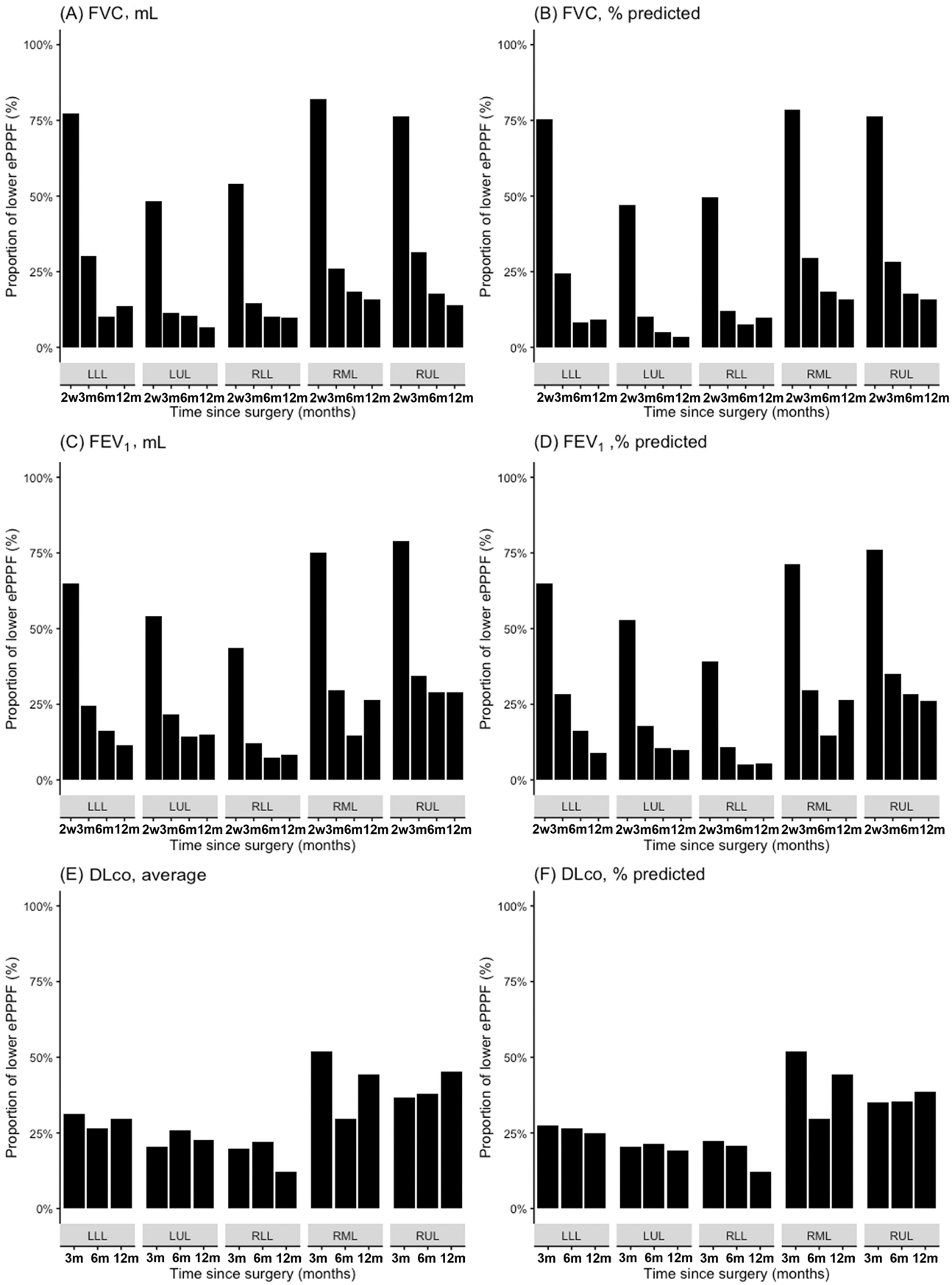


FIGURE 3 | The proportion of patients below the predicted postoperative pulmonary function. LLL, left lower lobe; LUL, left upper lobe; RLL, right lower lobe; RML, right middle lobe; RUL, right upper lobe.

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TABLE 2 | Factors associated with failure to reach predicted postoperative pulmonary function at 6 months after surgery ($N = 419$).

	Non-recovery of FVC (% predicted)	Non-recovery of FEV_1 (% predicted)	Non-recovery of DLCO (% predicted)
	Adjusted odds ratio (95% CI)[a]	**Adjusted odds ratio (95% CI)[a]**	**Adjusted odds ratio (95% CI)[a]**
Baseline factors			
Sociodemographics and behaviour			
Age, year (per 10 years)	0.98 (0.68–1.43)	0.81 (0.59–1.11)	0.94 (0.72–1.21)
Sex, men (vs. women)	1.49 (0.34–5.34)	1.22 (0.37–3.51)	0.42 (0.15–1.10)
Body mass index, kg/m^2	**0.87 (0.77–0.98)**	1.01 (0.91–1.11)	0.96 (0.89–1.04)
Smoking status, ever smoker (vs. never)	1.15 (0.34–4.91)	0.75 (0.26–2.42)	1.13 (0.43–3.29)
Comorbidities			
COPD, yes (vs. none)	0.91 (0.37–2.11)	0.61 (0.25–1.38)	0.81 (0.39–1.60)
Hypertension, yes (vs. none)	0.75 (0.33–1.61)	1.22 (0.63–2.32)	1.15 (0.66–1.97)
Diabetes mellitus, yes (vs. none)	0.46 (0.11–1.40)	0.55 (0.18–1.40)	0.89 (0.41–1.81)
Clinical factors			
Adenocarcinoma, yes (vs. others)	0.95 (0.37–2.71)	1.87 (0.71–5.72)	1.34 (0.56–3.61)
Open surgery, yes (vs. VATS)	1.89 (0.74–4.49)	**3.17 (1.43–6.81)**	0.69 (0.28–1.52)
PPC, yes (vs. none)	1.44 (0.62–3.13)	0.61 (0.25–1.36)	1.27 (0.65–2.41)
Location of surgery			
RLL	*Reference*	*Reference*	*Reference*
LLL	1.04 (0.25–3.9)	3.28 (0.97–12.92)	1.34 (0.57–3.09)
LUL	0.65 (0.16–2.44)	1.94 (0.57–7.63)	1.09 (0.48–2.44)
RML	3.59 (0.93–13.56)	3.25 (0.71–14.97)	2.04 (0.72–5.55)
RUL	2.18 (0.88–6.19)	**6.6 (2.48–22.91)**	**2.18 (1.14–4.32)**
Lung function test			
FVC, % predicted (per 10% lower)	—	0.91 (0.72–1.15)	0.99 (0.81–1.22)
FEV1, % predicted (per 10% lower)	0.92 (0.71–1.19)	—	1.00 (0.84–1.21)
DLco, % predicted (per 10% lower)	0.87 (0.70–1.09)	0.82 (0.67–0.99)	—
Change factors from baseline to 2 weeks after surgery			
MVPA			
Persistent ≥ 30 min/day	*Reference*	*Reference*	*Reference*
Increased from < 30 min/day to ≥ 30 min/day	1.28 (0.36–4.11)	0.94 (0.35–2.32)	0.95 (0.41–2.12)
Decreased from ≥ 30 min/day to < 30 min/day	1.58 (0.64–4.15)	1.07 (0.51–2.24)	**1.89 (1.03–3.56)**
Persistent < 30 min/day	1.64 (0.64–4.45)	0.88 (0.40–1.93)	1.1 (0.56–2.17)

Note: The Bold values denote statistical significance (two-sided $p < 0.05$) and indicates that the 95% CI does not include 1.00.
Abbreviations: COPD, chronic obstructive pulmonary disease; LLL, left lower lobe; LUL, left upper lobe; MVPA, moderate-to-vigorous physical activity; PPC, postoperative pulmonary complication; RLL, right lower lobe; RML, right middle lobe; RUL, right upper lobe; VATS, video-assisted thoracoscopic surgery.
[a]Adjusted for age, sex, body mass index, smoking status, VATS, and PPCs.

OR = 6.60, 95% CI = 2.48–22.91) and DLCO (% predicted) (adjusted OR = 2.18, 95% CI = 1.14–4.32) with the reference of the right lower lobectomy. Decreased MVPA from ≥ 30 min/day at baseline to < 30 min/day at 2 weeks after surgery was related to non-recovery of DLCO (% predicted) (adjusted OR = 1.89, 95% CI = 1.03–3.56) with the reference of those with persistent MVPA (Table 2).

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3.5 | Association Between PPO Lung Function and Complications

To further investigate whether PPO spirometry measures correlated with early surgical outcomes, we analysed 30-day postoperative complications in relation to PPO-FEV_1, FVC, and DLCO, both overall and stratified by resected lobe (Table S4). Lower PPO-FEV_1 and DLCO were significantly associated with an increased risk of complications. After adjusting for age, sex, BMI, cancer stage, smoking history, VATS, and resected lobe, the adjusted odds ratio for complications per 10% decrease in PPO-FEV_1 was 1.48 (95% CI 1.12–1.95), and for PPO-DLCO was 1.35 (95% CI 1.05–1.73). Notably, the association was strongest in patients who underwent left lower lobectomy, with an adjusted OR of 15.7 (95% CI 1.02–242.7) for PPO-FEV_1, and in those who underwent left upper lobectomy, with an adjusted OR of 7.37 (95% CI 1.00–54.57) for PPO-DLCO.

4 | Discussion

These findings provide important insights into the postoperative changes in pulmonary function, emphasising the importance of the lobe-specific variation. By comparing the actual changes in pulmonary function to predictions made using the traditional segmental method, we observed that the LUL and RLL resections yielded pulmonary function values similar to those of PPO values as early as 2 weeks after surgery and observed pulmonary function values exceeded PPO values across all lobes at 3 months after surgery. Factors such as surgical approach (open vs. video-assisted thoracoscopic surgery), right upper lobectomy in the reference of right lower lobectomy, and postoperative physical activity change from baseline to 2 weeks after surgery significantly influenced non-recovery of lung function at 6 months after surgery.

Early postoperative decline in lung function, particularly in FVC, FEV_1, and DLCO, was observed across all lobes except the RML, with an approximate 25% reduction in lung function at 2 weeks postoperatively, regardless of the number of segments in the lobe. In contrast, the traditional segmental method predicts that the LUL, LLL, RUL, RML, and RLL should contribute 26.3%, 21.1%, 15.8%, 10.5%, and 26.3%, respectively, to lung function. During the immediate postoperative period, lung function significantly decreased regardless of the resected lobe. General anaesthesia causes microatelectasis and reduces functional residual capacity. In addition, surgical incision and postoperative pain affect chest wall compliance and lead to a decline in pulmonary function. Notably, from the third month postsurgery, lung function improved beyond the levels predicted by the traditional segmental method, regardless of the lobe resected [10, 25].

In this study, right upper lobectomy was significantly associated with a lack of recovery of FEV_1 (% predicted) to PPO levels relative to recovery after resection of the other lobes with the reference of right lower lobectomy. Lobe-specific variability in the recovery of pulmonary function may have several possible explanations. First, after right upper lobectomy, the RML tends to shrink owing to several factors, including incomplete development of the horizontal fissure and damage to the interlobar veins. Additionally, the upward displacement of the remaining lung can change the bronchial angle, leading to bronchial kinking, which results in decreased postoperative lung function [12, 26, 27]. These issues can lead to a reduction in the volume of the middle lobe, exacerbating overall volume and functional loss. Second, greater lung resection is thought to promote a compensatory response, which impacts the functional recovery of lung function through the expansion of the remaining lung and increased perfusion and ventilation. Ueda et al. [11] reported that this compensatory response appeared to be more robust after lower lobectomy than after upper lobectomy. But in another study, the 3D-computed tomography (CT) measured volume of the lower lobe was smaller than that of the upper lobe; the upper lobe possibly has more alveolar-capillary reserves than the lower lobe to be recruited postoperatively [28]. The compensatory growth observed in the ipsilateral and contralateral lung, as suggested by 3D-CT volumetry, highlights the body's ability to adapt to reduced lung volume [12, 29]. This ability to compensate for the loss of lung tissue might explain why lung function eventually surpasses the PPO levels after the initial postoperative period. Korst et al. reported paradoxical improvement in pulmonary function following RUL in a subset of patients with severe chronic obstructive pulmonary disease, potentially reflecting volume reduction of diseased segments and "decompression" of healthier lung tissue. However, given that our cohort predominantly comprised early-stage NSCLC patients with normal or mild-to-moderate airflow limitation, removal of relatively healthy parenchyma might produce a net functional deficit, explaining our findings [30].

Our study also identified factors that contribute to variability in postoperative outcomes. For example, open surgery, as opposed to VATS, is associated with a greater risk of not achieving PPO for FEV_1, underscoring the potential benefits of minimally invasive techniques for preserving pulmonary function. Additionally, while demographic factors such as age, sex, smoking status, and comorbidities such as chronic obstructive pulmonary disease are critical for overall patient management, they did not significantly influence the recovery of pulmonary function after surgical resection in our cohort. Instead, maintaining or increasing postoperative MVPA may improve recovery rates, highlighting the importance of incorporating physical rehabilitation into postoperative care plans.

Notably, the presumed universal superiority of lobectomy has been challenged by recent phase 3 randomised trials [4, 5], which demonstrated that sublobar resection—either segmentectomy or wedge resection—can achieve survival outcomes that are non-inferior to those of lobectomy in patients with small and peripheral NSCLC. Additionally, these studies specifically reported higher or better-maintained postoperative FEV_1 and DLCO values in patients undergoing sublobar resections than those with conventional lobectomy. Although our current findings focus on lobe-specific variations within standard lobectomies, the emerging evidence suggests that the choice of surgical extent itself may critically influence functional recovery. This highlights the importance of tailoring surgical strategies to individual patients based on tumour size, anatomical location, and baseline pulmonary function.

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Despite these insights, this study has several limitations. The single-centre design may limit the generalisability of our findings to more diverse populations. The 12-month follow-up period provides valuable short- to mid-term recovery data but does not capture long-term outcomes. Additionally, although key pulmonary function measures were the focus of this study, other physiological parameters such as the cardiopulmonary exercise test and six-minute walk test that could provide a more comprehensive understanding of recovery were excluded. Excluding patients with incomplete follow-up could introduce a selection bias, potentially skewing the results to those with better recovery outcomes.

In conclusion, our study showed different postoperative lung function recovery based on the resected lobe for NSCLC, emphasising the importance of the lobe-specific variation. By understanding the variability in outcomes based on the resected lobe, surgical approach, and change of physical activity from baseline to 2 weeks after surgery, future studies should explore these factors in larger and more diverse populations to refine the predictive models and enhance surgical care protocols.

Author Contributions

Yeong Jeong Jeon: conceptualization (equal), writing – original draft (equal), writing – review and editing (equal). **Sumin Shin:** data curation (equal), writing – original draft (equal), writing – review and editing (equal). **Sunga Kong:** data curation (equal), resources (equal), writing – review and editing (equal). **Seongwoo Yang:** formal analysis (equal), software (equal). **Jong Ho Cho:** data curation (equal), resources (equal), writing – review and editing (equal). **Hong Kwan Kim:** data curation (equal), resources (equal), writing – review and editing (equal). **Young Mog Shim:** data curation (equal), resources (equal), writing – review and editing (equal). **Danbee Kang:** methodology (equal), visualization (equal), writing – review and editing (equal). **Hye Yun Park:** conceptualization (equal), methodology (equal), writing – review and editing (equal).

Ethics Statement

The study protocol was approved by the Institutional Review Board of the Samsung Medical Center (IRB no. 2015–11–025). Written informed consent was obtained from all participants.

Conflicts of Interest

The authors declare no conflicts of interest.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** Adjusted mean (SE) of pulmonary function at baseline and 2 weeks, 3, 6, and 12 months after surgery. **Table S2:** Changes in pulmonary function from baseline to 2 weeks, 3, 6, and 12 months after surgery. **Table S3:** Differences between the change in PPO pulmonary function from baseline to 2 weeks, 3, 6, and 12 months after surgery. **Table S4.** Association between predicted postoperative lung function and 30-day postoperative complications, overall and stratified by surgical lobe.

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