Original Article

Recovery of pulmonary function after lung wedge resection

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Background: Pulmonary function following lung wedge resection is not fully understood. This study aimed to assess the influence of wedge resection upon postoperative pulmonary function.

Methods: We retrospectively evaluated pulmonary function at 3, 6, and 12 months postoperatively in 29 patients who underwent lung wedge resection. The values of the pulmonary function tests (PFTs) were compared among the time points using a paired *t*-test.

Results: The vital capacity (VC) values before surgery and at 3, 6 and 12 months postoperatively were 2,994±793, 2,845±799, 2,941±801, and 2,964±839 mL, respectively. The VC decreased at 3 months postoperatively (P=0.002) and recovered by 6 and 12 months postoperatively (P=0.003 and 0.003, respectively). The VC values at 6 and 12 months postoperatively did not significantly differ from that before surgery (P=0.152 and 0.361, respectively). The forced expiratory volume in one second (FEV_1) values before surgery and at 3, 6, and 12 months postoperatively were 2,156±661, 2,034±660, 2,091±672 and 2,100±666 mL, respectively. The values decreased at 3 months postoperatively (P<0.001) and recovered; however, they remained lower than the preoperative value (P=0.036).

Conclusions: The postoperative VC decreased temporarily but recovered to near the preoperative level after 12 months. We concluded that the loss of VC following lung wedge resection is minimal. These findings are beneficial for planning surgery and explaining the procedure to patients who are undergoing lung wedge resection.

Keywords: Wedge resection; respiratory function tests; vital capacity (VC); forced expiratory volume

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Introduction

Lung wedge resection is a non-anatomical resection that differs from a lobectomy or segmentectomy. Lung wedge resection is indicated for several diseases such as lung cancer, metastatic lung tumors, benign lung tumors, and non-definitive diagnosed nodules. Wedge resection in lung cancer is sometimes indicated in patients with marginal pulmonary function, high risk patients and elderly patients (1). If the phase III study of wedge resection in peripheral ground glass opacity dominant lung cancer demonstrates a positive result, it is expected that the indications for wedge resection will be expanded (2).

The prediction of postoperative pulmonary function is important for the evaluation for operative tolerance, the risk of postoperative complications, long-term quality of life of the patient, to determine the resectable volume of the lung and to plan the surgical procedure (3,4). The prediction of postoperative pulmonary function is calculated from the number of resected lung segments in cases of lobectomy or segmentectomy. Since wedge resection is non-anatomical, it is unclear as to what extent the lung volume can be practically resected, and there is no standard method to calculate the predicted postoperative pulmonary function. Some studies have reported that a lobectomy resulted in a greater decrease in postoperative pulmonary function than segmentectomy or wedge resection (5,6). However, the details of postoperative pulmonary function after lung wedge resection are not well understood. It is therefore necessary to understand how the patient's pulmonary function is altered with time and determine the extent of recovery.

The aim of this study was to assess the influence of wedge resection on postoperative pulmonary function.

Methods

Patients

Wedge resection was indicated for patients with suspicious benign nodules, metastatic lung tumors, an inflammatory lung nodule and pre-invasive adenocarcinoma of the lung that was diagnosed using radiological findings in case of pure ground glass nodule or part solid ground glass nodule with the solid component of less than 5 mm. Patients who had undergone any lung resection were asked to attend postoperative pulmonary function tests (PFTs) at 3, 6 and 12. Patients who had undergone lung wedge resection between January 2016 and December 2017 at the Jikei University Hospital in Tokyo, Japan, were retrospectively analyzed and those patients whose data included four PFTs (preoperative and postoperative 3, 6, and 12 months) were included in this study. Patients who missed any of the PFTs were excluded. Patient clinical demographic and perioperative information, including age, sex, smoking history, comorbidities, lung computed tomography (CT) findings, past history of thoracotomy, disease, size of the resected lesions, procedure (thoracotomy or thoracoscopic surgery, number and location of resections), operative time, intrathoracic adhesion, number, total length of staplers used, use of absorbability sheet and fibrin glue, postoperative complications, preoperative and postoperative PFTs [vital capacity (VC) and forced expiratory volume in one second (FEV_1)] and details of the leading surgeon were collected from a prospective database or the patients' medical records. The %VC and %FEV_1 (measured value/standard value rate) were calculated with the LMS method, which was modified for Japanese patients, as recommended by the Japanese Respiratory Society (7).

Ethical considerations

Informed consent was obtained from all patients after explaining the surgical indication, risks, and benefits, and other surgical procedures and treatments. All procedures that were performed during this study were in accordance with the ethical standards of our institutional review board and the Declaration of Helsinki and its later amendments. The Ethics Committee of Jikei University School of Medicine approved this study (approval number: 30-243 [9264]) and waived the need for obtaining individual patient consent for this retrospective study.

Statistical analyses

We calculated the differences among the preoperative value and the postoperative values of VC and FEV_1 at each time point (3, 6, and 12 months), which are expressed as ΔVC and ΔFEV_1, respectively. We also calculated the postoperative/preoperative pulmonary function ratios of the VC and FEV_1 values at each time point, which are expressed as recovery ratios (RRs), in order to evaluate the chronological change in the ratio from baseline in each patient. We compared the values of the VC or FEV_1 and the RRs of the VC or FEV_1 among the time points using a paired *t*-test. Paired *t*-tests for the RRs of the VC or FEV_1 were performed by setting the preoperative value to 100%. A 120 mL decrease in VC and FEV_1 was considered to be clinically meaningful when comparing different of preoperative and postoperative value. We calculated that a sample size of 24 patients would provide a power of 80% in the detection of a 120 mL mean decrease in the VC and FEV_1, with a type I error of 5%. For power analysis, we used a standard deviation (SD) of 200 mL of ΔVC and ΔFEV_1. We assessed the correlations between clinical factors and the RRs of the VC or FEV_1 at 12 months postoperatively using an independent *t*-test in order to elucidate risk factors for loss of pulmonary function. We used JMP version 13.0.0 (SAS Institute, Cary, NC, USA) to perform the statistical analyses. P values <0.05 were considered statistically significant.

Results

Patient characteristics

One-hundred and twenty patients underwent lung wedge resection and of those, 29 patients had available and

Table 1 Characteristics of the 29 patients after lung wedge resection

Characteristic	n	(%)
Sex		
Male	16	55
Female	13	45
Age (mean ± SD, years)	66±15	
Smoking history		
Yes	17	59
No	12	41
Respiratory comorbidity		
Yes	15	52
Bronchial asthma	3	
Pulmonary emphysema	8	
Pulmonary fibrosis	6	
Chronic pulmonary infections	3	
No	14	48
Past thoracotomy		
Yes	6	21
No	23	79
Preoperative %VC		
<80	6	21
≥80	23	79
Preoperative %FEV_1		
<80	10	34
≥80	19	66
Resected disease		
Lung cancer	12	41
Pulmonary metastasis	10	35
Benign lung disease	7	24
Surgical side, site		
Right	16	55
Upper lobe	6	
Middle lobe	1	
Lower lobe	9	
Left	13	45
Upper lobe	9	
Lower lobe	4	
Size of resected tumors (mean ± SD, mm)	16±7	
Surgical approach		
Thoracoscope	28	97
Thoracotomy	1	3
Intrathoracic adhesion		
Yes	8	28
No	21	72
Number of resected lesions		
1	24	83
2	4	14
3	1	3
Number of staplers used (mean ± SD)	4±2	
Total length of staplers used (mean ± SD, mm)	194±83	
Absorbable reinforcement sheet		
Yes	14	48
No	15	52
Fibrin glue		
Yes	8	28
No	21	72
Operative time (mean ± SD, min)	94±41	

SD, standard deviation; VC, vital capacity; FEV_1, forced expiratory volume in one second.

complete PFTs data. Reasons for excluded cases were that patients did not agree to undergo regular PFTs, patients did not visit for follow-up, follow-up was completed ahead of the 12 month time frame or the doctor in charge omitted tests at his/her discretion.

Table 1 provides the characteristics of the 29 patients. The mean and SD of the age at the time of surgery was 66±15 years. Fifteen patients had respiratory comorbidity and of those five patients had more than two comorbidities. The means and SDs of the preoperative %VC and %FEV_1 were 92.1%±13.4% and 87.3%±15.4%, respectively. Twelve patients had lung cancer and the reasons of indication for

Table 2 Chronological changes in the vital capacity and forced expiratory volume in one second

Pulmonary function test	Preoperative	Postoperative		
		3 months	6 months	12 months
VC (mL)	2,994±793	2,845±799	2,941±801	2,964±839
ΔVC (mL)		−149±228	−53±191	−30±171
Recovery ratio of VC (%)		94.9±7.6	98.2±6.4	98.8±5.6
FEV_1 (mL)	2,156±661	2,034±660	2,091±672	2,100±666
$ΔFEV_1$ (mL)		−121±150	−64±138	−56±135
Recovery ratio of FEV_1 (%)		94.2±7.8	96.9±6.3	97.2±6.4

Δ indicates differences between the preoperative value and each postoperative value. VC, vital capacity; FEV_1, forced expiratory volume in one second.

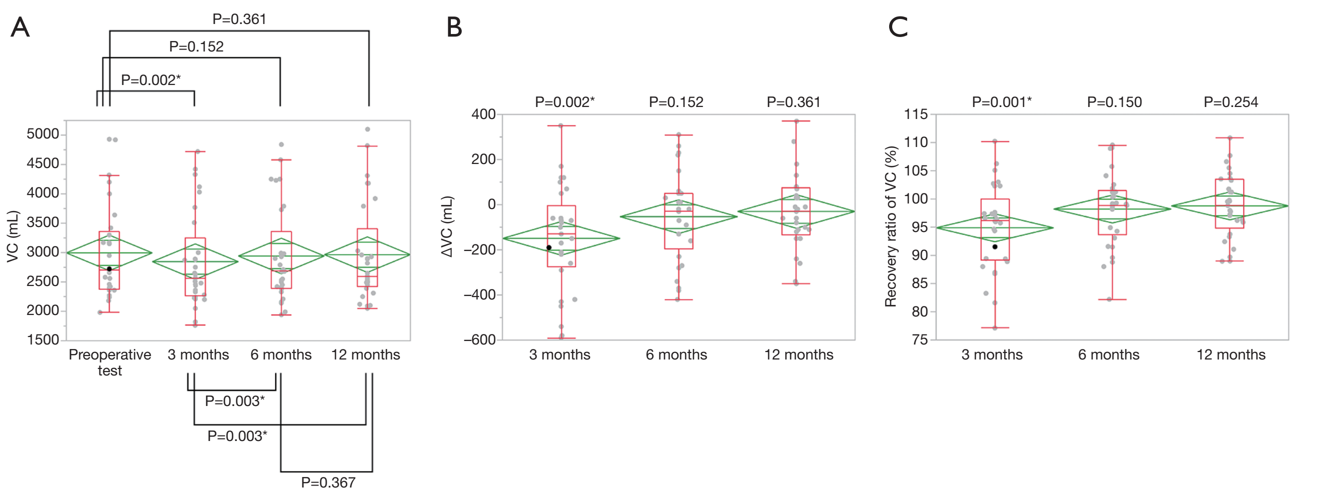

Figure 1 Chronological change in the vital capacity after lung wedge resection. *, indicates a significant difference. (A) The vital capacity (VC) decreased at 3 months compared to the preoperative value, and recovered at 6 and 12 months. (B,C) The recovery ratio and ΔVC were low at 3 months and gradually increased at 6 and 12 months, and reached a point where they did not significantly differ compared to the baseline.

wedge resection were suspicious pre-invasive lesion in 7 patients and borderline pulmonary function or other high risk factors in 5 patients. The mean and SD of the size of the resected lesions (the size of the largest lesion was taken in cases of multiple lesions) was 16±7 mm. All patients underwent thoracoscopic surgery, but intraoperative conversion to thoracotomy was necessary in one patient due to severe intrathoracic adhesion. Absorbable reinforcement sheets were used in 14 patients, and fibrin glue was also used in eight of these patients. Although one patient experienced postoperative pleuritis, he underwent chest tube thoracostomy and improved. The remaining patients experienced no postoperative complications. Our surgical team included staff surgeons and no residents. In this study, seven surgeons conducted surgeries as operators.

If these 29 patients had not undergone surgery, the mean reductions in the VC and FEV_1 of standard value, as calculated with the LMS method, over the course of 12 months were 22±9 and 20±7 mL, respectively.

Recovery of the VC

The means and SDs of the preoperative and 3-, 6-, and 12-month postoperative VC values were 2,994±793, 2,845±799, 2,941±801, and 2,964±839 mL, respectively (*Table 2*, *Figure 1A*). The ΔVC values at 3, 6, and

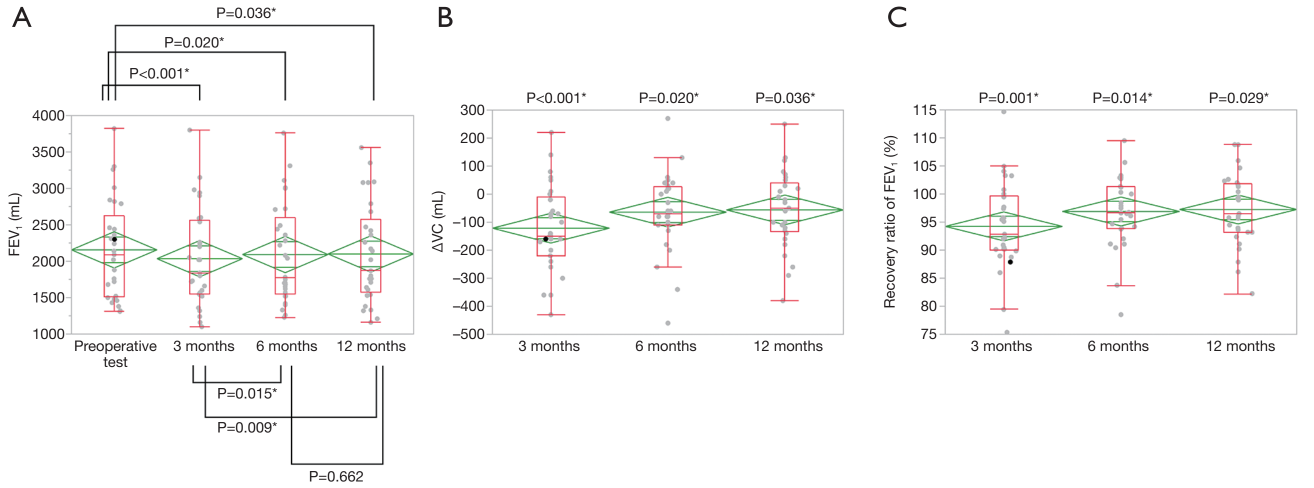

Figure 2 Chronological change in the forced expiratory volume in one second after lung wedge resection. * indicates a significant difference. (A) The forced expiratory volume in one second (FEV_1) decreased at 3 months, and recovered at 6 and 12 months. However, the FEV_1 at 12 months remained lower compared to the preoperative value. (B,C) The recovery ratio and ΔFEV_1 were low at 3 months and gradually increased at 6 and 12 months, but significantly lower compared to the baseline.

12 months postoperatively were −149±228, −53±191, and −30±171 mL, respectively (*Table 2*, *Figure 1B*). The RRs of the VC at 3, 6, and 12 months postoperatively were 94.9%±7.6%, 98.2%±6.4%, and 98.8%±5.6%, respectively (*Table 2*, *Figure 1C*). The VC at 3 months postoperatively was significantly reduced compared to the preoperative VC (P=0.002). The VC had recovered significantly at 6 and 12 months postoperatively (P=0.003 and 0.003, respectively). The RR of the VC at 3 months postoperatively was significantly lower compared to the baseline (P=0.001). The RR of the VC increased gradually at 6 and 12 months postoperatively, and reached a point where they did not significantly differ compared to the baseline (P=0.150 and 0.254, respectively).

Recovery of the FEV_1

The means and SDs of the preoperative and 3-, 6-, and 12-month postoperative FEV_1 were 2,156±661, 2,034±660, 2,091±672, and 2,100±666 mL, respectively (*Table 2*, *Figure 2A*). The ΔFEV_1 values at 3, 6, and 12 months postoperatively were −121±150, −64±138, and −56±135 mL, respectively (*Table 2*, *Figure 2B*). The RRs of the FEV_1 at 3, 6, and 12 months postoperatively were 94.2%±7.8%, 96.9%±6.3%, and 97.2%±6.4%, respectively (*Table 2*, *Figure 2C*). The FEV_1 was significantly reduced at 3 months postoperatively compared to the preoperative value (P<0.001). The FEV_1 had recovered significantly at 6 and 12 months postoperatively (P=0.015 and 0.009, respectively). However, the FEV_1 at 6 and 12 months postoperatively remained significantly lower than the preoperative value (P=0.020 and 0.036, respectively). The RR of the FEV_1 at 3 months postoperatively was significantly lower compared to the baseline (P=0.001). Although the RR of the FEV_1 increased gradually, the RRs at 12 months remained significantly lower compared to the baseline (P=0.014 and 0.029, respectively).

Factors related to postoperative pulmonary function

Table 3 presents the results of univariate analysis of the factors related to changes in the pulmonary function at 12 months postoperatively compared to the preoperative value. The RR of the VC was significantly preserved in patients with tumors ≥20 mm in size compared to that in patients with tumors <20 mm in size (101.7% *vs.* 97.0%, respectively; P=0.027). Although the difference was not significant, the VC was relatively preserved in patients aged <70 years compared to that in patients aged ≥70 years (100.0% *vs.* 96.7%, respectively; P=0.079). The RR of the FEV_1 was significantly preserved in patients aged <70 years compared to that in patients aged ≥70 years (99.5% *vs.* 94.5%, respectively; P=0.035). Preoperative %VC and $\%FEV_1$ were not significant factors for the recovery rate of

Table 3 Analysis of the factors associated with recovery of pulmonary function at 12 months postoperatively

Factors	n	VC		FEV_1	
		RR (%)	P	RR (%)	P
Sex			0.323		0.569
Male	16	99.7		97.9	
Female	13	97.6		96.5	
Age			0.079		0.035*
≥70	13	96.7		94.5	
<70	16	100.0		99.5	
Smoking history			0.160		0.741
Yes	17	97.5		96.9	
No	12	100.6		97.8	
Respiratory comorbidity			0.646		0.713
Yes	15	98.3		97.7	
No	14	99.3		96.8	
Past thoracotomy			0.798		0.656
Yes	6	99.3		98.3	
No	23	98.6		97.0	
Lobe			0.500		0.070
Upper or middle	16	98.1		95.3	
Lower	13	99.6		99.6	
Size of resected lesion			0.027*		0.715
≥20 mm	11	101.7		96.7	
<20 mm	18	97.0		97.6	
Preoperative %VC			0.824		0.920
≥80%	23	98.6		97.2	
<80%	6	99.2		97.5	
Preoperative %FEV_1			0.093		0.888
≥80%	18	100.1		97.4	
<80%	11	96.5		97.0	
Number of resected lesions			0.831		0.754
≥2	5	99.3		96.4	
1	24	98.7		97.4	
Number of staplers used			0.775		0.312
≥4	18	98.5		96.3	
1–3	11	99.2		98.8	
Absorbable reinforcement sheet			0.664		0.355
Yes	14	99.3		98.4	
No	15	98.3		96.1	
Fibrin sealant			0.102		0.827
Yes	8	96.0		97.7	
No	21	99.8		97.0	

*, indicates a significant difference. VC, vital capacity; FEV_1, forced expiratory volume in one second; RR, recovery ratio.

VC and FEV_1 from the baseline.

Discussion

The aim of this study was to evaluate the influence of wedge resection on postoperative pulmonary function, which has not been fully elucidated previously. There were two major findings in this study. First, the VC after lung wedge resection decreased temporarily but recovered to near the preoperative level after 12 months. Secondly, the FEV_1 after lung wedge resection decreased and recovered gradually over the course of 12 months but did not recover to preoperative level.

In this study, the VC after lung wedge resection decreased temporally and the RR of the VC at 3 months postoperatively was approximately 5%. The VC then recovered to near the preoperative level (approximately 99%) after 12 months. The mean loss of VC of standard value, as calculated with the LMS method, over the course of 12 months was 22±9 mL without lung resection, and the actual postoperative VC loss was −30±171 mL at 12 months. These results led us to believe that the potential volume of the remaining lung can compensate for the volume of the resected lung, to some extent. A previous study also reported the compensatory response of the remaining lung after lung resection and supports our conclusion of these results (8). In cases wherein the resected lung volume is small amount, such as in wedge resection compared to lobectomy, the VC will recover almost completely due to compensation. It can be concluded that the loss of VC after lung wedge resection is minimal.

The FEV_1 following lung wedge resection decreased at 3 months postoperatively and recovered gradually from 6–12 months. However, the FEV_1 did not recover to the preoperative level, in contrast to the VC. The mean loss of FEV_1 of standard value, as calculated with the LMS method, over the course of 12 months was 20±7 mL without lung resection, and the actual postoperative FEV_1 loss at 12 months was −56±135 mL, approximately twice the standard calculated decrease. We hypothesized that the difference in the degree of recovery of VC and FEV_1 suggests that damage to the respiratory muscles through surgery affects the FEV_1 more than the VC. Another study has compared postoperative PFTs between wedge resection and mediastinal procedure without lung resection and demonstrated that there was no significant difference in decrease of the PFTs index (9). A previous study reported that in patients with low FEV_1, a more invasive approach increased the postoperative complication rate (10). Although the relation is indirect, we hypothesized that damage to the respiratory muscle is a factor associated with a decrease in FEV_1.

The clinical factor of younger age was related to greater postoperative recovery of pulmonary function, in relation to both the VC and the FEV_1. We surmised that the potential volume of the remaining lung to compensate for postoperative pulmonary function is more preserved in younger patients. This may be because such patients experienced fewer effects of decreasing static lung compliance due to the loss of elastic lung tissue, increasing chest wall stiffness, and decreasing respiratory muscle strength with age (11). Patients with larger tumors exhibited greater recovery of VC. We hypothesized that once the intrathoracic space that had been occupied by the lesion was resected, the remaining lung expanded into the space and began to function. However, this concept is paradoxical to the general idea that larger lesions would require larger resections, which would thus be associated with a poorer recovery.

These major findings clarified the influence of lung wedge resection on postoperative pulmonary function. These findings are beneficial for planning surgery and explaining the procedure to patients undergoing lung wedge resection.

This study had some limitations. First, of the 120 patients who underwent wedge resection, the data from four PFTs, preoperatively and at 3, 6, and 12 months postoperatively, were only available for 29 patients. Thus, this study was potentially affected by bias. Second, the 29 patients had relatively normal PFT and thus their recovery may not reflect the result of patients with worse preoperative values. Although it was demonstrated that preoperative PFT did not relate to recovery rate, further investigations would be appropriate. In addition, the follow-up period of only 12 months does not explore the long-term outcomes of this investigation. A previous study reported that patients undergoing lung resection, including lobectomy and sublobar resection, recovered up to 12 months postoperatively, but at >12 months postoperatively the absolute values decreased with age but the %VC or $\%FEV_1$ did not decrease (5). In a future study, we plan to investigate whether long-term follow-up of patients who underwent wedge resection will yield the same results. Finally, only the VC and FEV_1 were used to assess postoperative pulmonary function in this study. Changes in the postoperative diffusing capacity or PFT in the immediate postoperative period, which have been reported to be useful predictors of postoperative risk, should be considered in future studies (12,13).

Conclusions

The VC following lung wedge resection decreased temporarily but recovered to near the preoperative level at 12 months postoperatively. The loss of VC after wedge resection is minimal. The FEV_1 after lung wedge resection decreased and recovered gradually over the course of 12 months but did not recover to the preoperative level. These findings are beneficial for planning surgery and explaining the procedure to patients undergoing lung wedge resection.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was approved by the Ethics Committee of Jikei University School of Medicine (approval number: 30-243 [9264]), and the need for informed consent was waived.

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