Original Article

Dynamic chest radiography in post-lobectomy recovery: a novel approach to evaluating pulmonary function and thoracic structures in patients with primary lung cancer

Kazuki Hayashi[1,2]^, Takuya Shiratori[1], Keiko Ueda[1], Keigo Okamoto[1]^, Yoko Kataoka[1]^, Yo Kawaguchi[1]^, Yasuhiko Ohshio[1], Jun Hanaoka[1]^

[1]Division of General Thoracic Surgery, Department of Surgery, Shiga University of Medical Science, Otsu, Japan; [2]Department of General Thoracic Surgery, Omi Medical Center, Kusatsu, Japan

Contributions: (I) Conception and design: K Hayashi, J Hanaoka; (II) Administrative support: J Hanaoka; (III) Provision of study materials or patients: All authors; (IV) Collection and assembly of data: K Hayashi, J Hanaoka; (V) Data analysis and interpretation: K Hayashi, J Hanaoka; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Kazuki Hayashi, MD. Division of General Thoracic Surgery, Department of Surgery, Shiga University of Medical Science, Seta Tsukinowa-cho, Otsu, Shiga 520-2192, Japan; Department of General Thoracic Surgery, Omi Medical Center, Kusatsu, Japan. Email: hayashikzk@gmail.com; hayashik@belle.shiga-med.ac.jp.

Background: Lobectomy for lung cancer leads to changes in thoracic structures and reduced pulmonary function, but real-time evaluation of compensatory mechanisms has been challenging. This study employed dynamic chest radiography to examine post-lobectomy changes in the projected lung area and excursion of diaphragm, as evaluated by sequential chest radiography, and determine their correlation with pulmonary function recovery.

Methods: This single-center and cross-sectional study was conducted at the Shiga University of Medical Science Hospital and included 65 patients who underwent lobectomy between May 2018 and December 2020. Dynamic chest radiography was performed preoperatively and at 1, 3, 6, and 12 months postoperatively alongside standard pulmonary function tests. We evaluated the postoperative trends in pulmonary function, projected lung area, and excursion of diaphragm. The results were analyzed using the Mann-Whitney *U* test and Fisher's exact test. Additionally, correlations between changes in the pulmonary function and dynamic chest radiography (DCR) parameters were assessed using Spearman's rank correlation coefficients. The utility of DCR in predicting postoperative pulmonary function recovery was further examined using receiver operating characteristic (ROC) curve analysis.

Results: Significant correlations were observed between the maximum projected lung area and pulmonary function recovery, particularly in upper lobectomy cases (correlation with vital capacity at 1 month postoperatively: r=0.72, P<0.01). This correlation was observed consistently across various surgical procedures, which suggests that early postoperative projected lung area measurements can predict pulmonary function recovery at 12 months. Excursion of diaphragm, especially in upper lobectomy cases, also showed a positive correlation with pulmonary function recovery (correlation with vital capacity at 1 month postoperatively: r=0.55, P<0.01). Receiver operating characteristic curve analysis validated the predictive capability of early postoperative projected lung area for long-term pulmonary function recovery with area under the curve of 0.815 [95% confidence interval (CI): 0.636–0.994] for upper lobectomy and 0.798 (95% CI: 0.564–0.982) for lower lobectomy groups.

^ ORCID: Kazuki Hayashi, 0000-0002-2393-1233; Keigo Okamoto, 0000-0002-6992-3765; Yoko Kataoka, 0000-0001-6268-6587; Yo Kawaguchi, 0000-0002-7828-4635; Jun Hanaoka, 0000-0002-5272-556X.

Conclusions: Dynamic chest radiography, which assessed the projected lung area and excursion of diaphragm, emerged as a promising non-invasive tool for monitoring post-lobectomy recovery and guiding rehabilitation efforts. These findings indicate its potential as an early predictor of pulmonary recovery, advocating for its integration into the perioperative care of patients with lung cancer. Future research should expand patient cohorts and refine predictive models using preoperative dynamic chest radiography to enhance post-lobectomy outcomes.

Keywords: Lung cancer; lobectomy; dynamic chest radiography (DCR); pulmonary function recovery; excursion of diaphragm

Submitted Aug 17, 2024. Accepted for publication Jan 03, 2025. Published online Feb 26, 2025.
doi: 10.21037/qims-24-1714
View this article at: https://dx.doi.org/10.21037/qims-24-1714

Introduction

Primary lung cancer remains the leading cause of cancer-related deaths worldwide (1), and several studies have been conducted to address this issue (2-5). Among the various treatment options available, surgery is the first choice for early-stage or locally advanced non-small cell lung cancer. It may also be considered under limited conditions or stages for small-cell lung cancer. Advancements in high-resolution computed tomography (CT) have made it possible to detect small lung cancers at an earlier stage. Although sublobar resection may be permissible based on CT characteristics, such as the ratio of the solid component to the whole tumor, lobectomy is recommended for tumors >2 cm in diameter (6,7). Lung resection inevitably results in a loss of lung volume in the patient, and postoperative pulmonary function tests show a decrease compared to preoperative values, which gradually recover over time (8,9). Several studies have investigated the factors and compensatory mechanisms that influence changes in pulmonary function following lung resection (10-16). These mechanisms include the elevation of the diaphragm and expansion of the remaining lung to compensate for the reduction in lung volume. However, reports linking changes in diaphragmatic motion and lung volume before and after surgery to the recovery of pulmonary function are limited (17,18). On the other hand, Kocjan *et al.* evaluated diaphragmatic motion using ultrasound in patients who underwent lung resection and demonstrated that the upper lobectomy group was associated with greater diaphragmatic dysfunction than the lower lobectomy group (19).

Recently, dynamic chest radiography (DCR), which produces radiographic images with high spatial and temporal resolution, was developed, enabling the dynamic observation of intrathoracic structures (Video S1) (20-22). Various reports using DCR have included analyses of the projected lung area, excursion of diaphragm, and diaphragmatic velocity in healthy individuals; studies on patients with chronic obstructive pulmonary disease (COPD) or interstitial pneumonia; and analyses of changes in lung perfusion during lung cancer surgery (23-33). The use of DCR allows for the tracking and analysis of changes in projected lung area and diaphragmatic motion before and after lung resection.

This study aimed to examine the progression of projected lung area and excursion of diaphragm using DCR in patients who underwent lobectomy for primary lung cancer and to evaluate the correlation with pulmonary function test results, thereby identifying changes in intrathoracic structures that may influence the recovery of respiratory function after lobectomy. The study specifically compared and assessed the outcome of upper and lower lobectomy procedures. We present this article in accordance with the STROBE reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-24-1714/rc).

Methods

Study population

This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Ethics Committee of Shiga University of Medical Science (No. CRB 5180008; October 10, 2017) and registered as a clinical trial (https://center6.umin.ac.jp/cgi-open-bin/icdr_e/ctr_view.cgi?recptno=R000033957, UMIN000029716). Participants were recruited from among patients who underwent surgical treatment for primary lung cancer at Shiga University of Medical Science Hospital

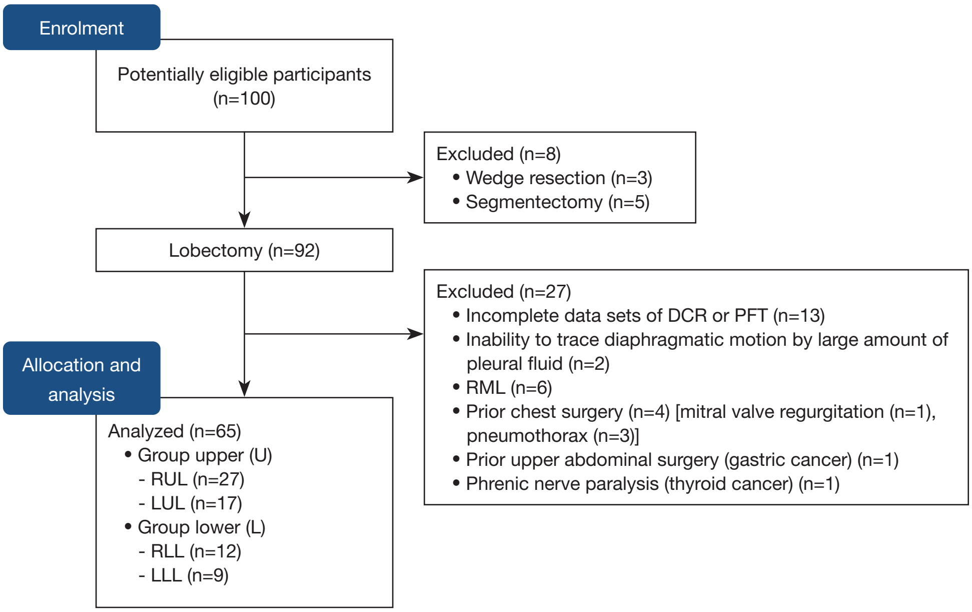

Figure 1 Study population flow diagram. DCR, dynamic chest radiography; LUL, left upper lobectomy; LLL, left lower lobectomy; PFT, pulmonary function test; RUL, right upper lobectomy; RLL, right lower lobectomy; RML, right middle lobectomy.

between May 2018 and December 2020. Written informed consent was obtained from all patients using a descriptive informed consent form. Patients adhered to the DCR protocols included in the study. From the initial cohort of 100 patients, the following were excluded: those who underwent wedge resection (n=3), segmentectomy (n=5), withdrew from the study (n=13), had substantial pleural effusion that made it difficult to evaluate diaphragmatic motion (n=2), or underwent middle lobe resection of the right lung (n=6; because of the small volume of lung resection and the small number of patients). In addition, we excluded patients with prior thoracic surgery (n=4; one mitral valve regurgitation and three pneumothorax surgeries), upper abdominal surgery (n=1; gastric cancer), and phrenic nerve paralysis following thyroid cancer surgery (n=1). Consequently, in this cross-sectional study, 65 patients (comprising 27 right upper, 12 right lower, 17 left upper, and 9 left lower lobectomies) were included in the final analysis (*Figure 1*). Data regarding patient demographics and clinical characteristics, including sex, body mass index (BMI), respiratory comorbidities, and the type of surgical intervention (video-assisted thoracoscopic surgery or thoracotomy) were extracted from electronic medical records. This study was based on the 8th edition of the Union for International Cancer Control/American Joint Committee on Cancer (UICC/AJCC) primary tumor, regional LNs involvement, and distant metastases (TNM) staging system (34).

DCR protocol

A Konica Minolta prototype (Konica Minolta, Inc., Tokyo, Japan) was used for the posterior-anterior DCR. The system comprised an indirect-conversion flat-panel detector (PaxScan, 4343CB, Varex Imaging Corporation, Salt Lake City, UT, USA), an X-ray tube (RAD-94/B-130H, Varian Medical Systems, Inc. 94/B- 130H, Varian Medical Systems, Inc., Palo Alto, CA, USA) and a pulsed X-ray generator (EPS45RF, EMD Technologies, Saint-Eustache, Canada). All participants were scanned in a sitting position during calm breathing with the following settings: X-ray tube voltage: 100 kV; X-ray tube current: 40 mA; pulse X-ray exposure time: 5 ms; distance from X-ray source to image: 2 m; additional filter: 0.5 mm Al + 0.1 mm Cu. The matrix size was 1,024×1,024 pixels, pixel size was 417 µm × 417 µm, and total image area was 42.7 cm × 42.7 cm. The pixel value range for each flat-panel detector pixel was 65,536 (16 bits). However, the pixel values saturated at approximately 58,000, corresponding to an incident surface dose of approximately 1.5 µGy (pulsed X-rays protected the participants from

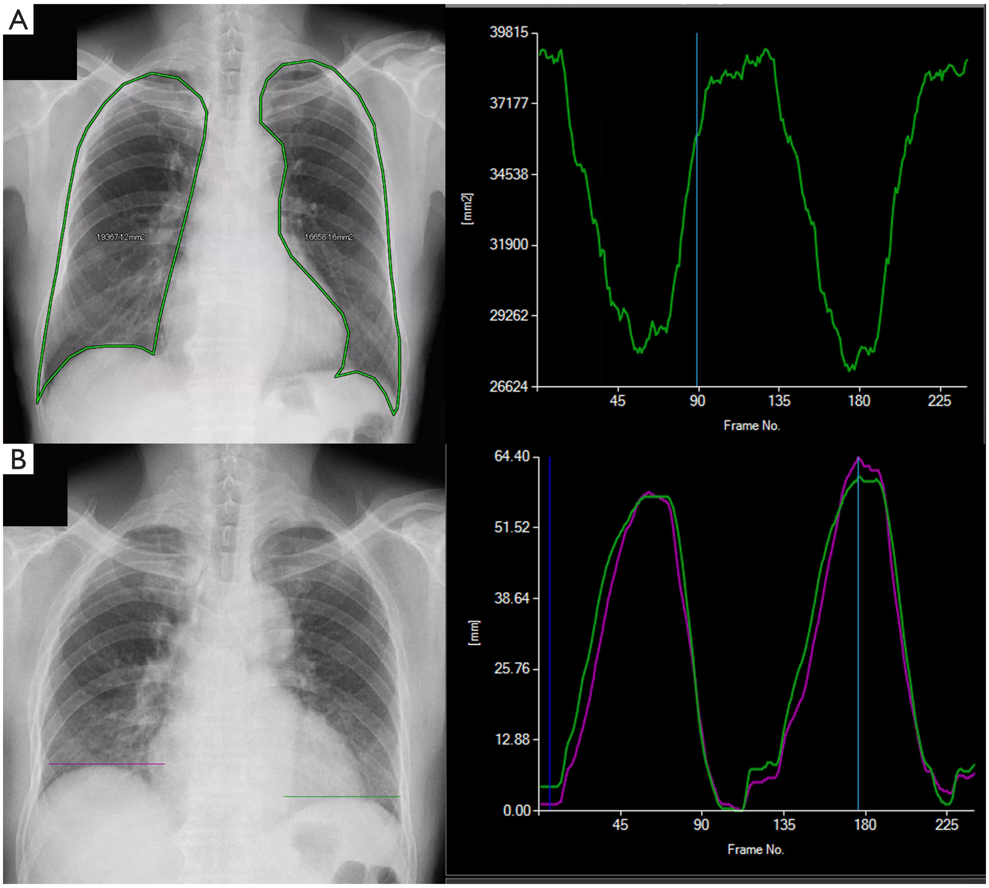

Figure 2 An example of the screen displayed at the dynamic chest radiography workstation. (A) Automatic analysis of the projected lung area. The areas of the right and left lung fields at each time phase are traced using a green frame, allowing dynamic observation of changes in the lung field area throughout a breathing cycle. The right side displays a graph showing changes in the projected lung area. (B) Dynamic analysis of diaphragmatic motion. The peak of the right diaphragm is indicated by a purple bar, and the peak of the left diaphragm by a green bar, enabling dynamic observation of diaphragmatic movement throughout a breathing cycle. The right side displays a graph showing changes in the excursion of diaphragm separately for the right and left diaphragm.

excessive radiation exposure). The total radiation dose was set below the International Atomic Energy Agency guidance level of 1.5 mGy for both chest radiograph posterior-anterior and chest radiograph lateral imaging. DCR was performed preoperatively and at 1, 3, 6, and 12 months postoperatively.

Evaluation of the projected lung area and excursion of the diaphragm

The DCR data were processed on a dedicated workstation, and the lung field contours were automatically tracked. Instances where gastrointestinal gas or intestinal content was mistaken for lung tissue were manually corrected by two thoracic surgeons (K.H. and J.H.). Based on the outlined lung contours, the software automatically calculated the left and right lung field areas (projected lung areas). The projected lung areas over two respiratory cycles (inhalation and exhalation) were computed and depicted as curves. The largest and smallest areas were identified as the maximal and minimal lung fields, respectively (*Figure 2A*).

In addition, the highest points of the diaphragmatic domes were automatically identified. If errors in recognition occurred due to gastrointestinal gas or pleural effusion, manual correction was performed by the aforementioned thoracic surgeons (K.H. and J.H.). The highest points on both sides were tracked automatically across the two respiratory cycles, and the vertical movement from the

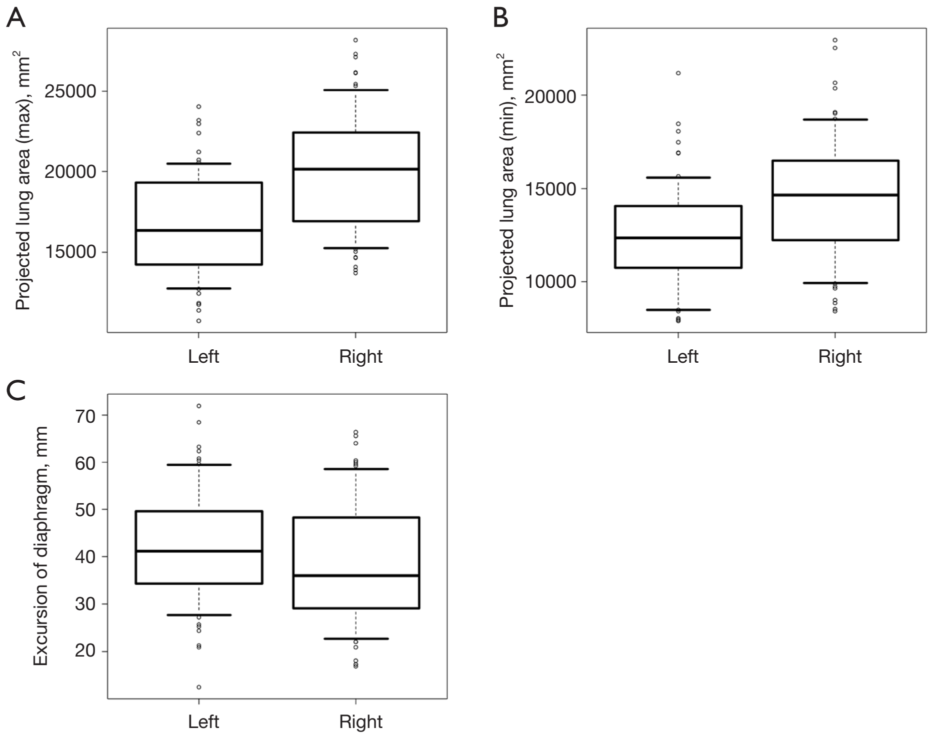

Figure 3 Preoperative values of dynamic chest radiography. (A) Projected lung areas (max). (B) Projected lung areas (min). (C) Excursion of diaphragm.

lowest position in a series of phases was calculated as the excursion of diaphragm. In addition, a curve was plotted to depict this measurement, with the greatest vertical movement recorded as the maximum excursion of diaphragm (*Figure 2B*).

Pulmonary function tests

All patients underwent respiratory function testing using a computerized spirometer (FUDAC-77; Fukuda Denshi Co., LTD, Tokyo, Japan) on the same day as DCR. Respiratory function test parameters included vital capacity (VC), %VC, forced vital capacity (FVC), %FVC, forced expiratory volume in 1 s (FEV1), %FEV1, forced expiratory volume percent in 1 s divided by forced vital capacity (FEV1%), diffusing capacity of the lungs for carbon monoxide (DL_{CO}), %DL_{CO}, diffusing capacity divided by the alveolar volume (DL_{CO}/V_A), and %DL_{CO}/V_A values. The diffusing capacity was measured using the single-breath method. Similar to DCR, respiratory function tests were performed preoperatively and at 1, 3, 6, and 12 months postoperatively.

Statistical analysis

All statistical analyses were conducted using EZR in R software (Saitama Medical Center, Jichi Medical University, Saitama, Japan) (35). Preoperative DCR data were reported separately for the left and right sides, while the postoperative data were reported separately for the affected (surgical) and unaffected sides. To adjust for interpatient differences, we compared the postoperative DCR and pulmonary function test results using the ratio (postoperative/preoperative).

$$\begin{aligned}&Rate\ of\ change\ in\ DCR\ results\ at\ POM\ x = \frac{DCR\ results\ at\ POM\ x}{DCR\ results\ at\ pre\text{-}operation}^{(x=1,3,6,12)}\\&Rate\ of\ change\ in\ pulmonary\ functiontest\ results\ at\ POM\ x = \frac{Pulmonary\ functiontest\ results\ at\ POM\ x}{Pulmonary\ functiontest\ results\ at\ pre\text{-}operation}^{(x=1,3,6,12)}\end{aligned} \quad [1]$$

Comparisons of patient background and pulmonary function test results between the upper (U) and lower (L) groups, as well as preoperative DCR metrics for the left and right sides, were performed using the Mann-Whitney *U* test for continuous variables and Fisher's exact test for nominal variables. Spearman's rank correlation coefficients were calculated to evaluate the presence and strength of correlations between the preoperative ratios of the DCR metrics and the pulmonary function test results at each postoperative time point. In addition, the receiver operating characteristic (ROC) curve was plotted, and area under the curve (AUC) was calculated to determine whether the DCR metrics (maximum projected lung area in the first postoperative month) could predict pulmonary function VC at 12 months postoperatively. Given the differences in the degree of VC recovery between the U and L groups, preoperative values of 0.97 for the U group and 0.90 for the L group were used as references. Statistical significance was set at $P<0.05$.

Results

Demographic data and preoperative pulmonary function tests

The patient background and preoperative pulmonary function test results are presented in *Table 1*. No significant differences were observed in any of the respiratory function test results.

Preoperative DCR

The preoperative DCR metrics are shown in *Figure 3* (detailed values are provided in Table S1). Regarding the projected lung area, both the maximum and minimum areas were significantly larger on the right side than on the left ($P<0.01$). Regarding the excursion of the diaphragm, although no statistically significant difference was observed, a trend towards greater excursion on the left side than the right side was observed ($P=0.08$).

Postoperative changes in pulmonary function test results

The progression of VC and %VC in postoperative pulmonary function tests is shown in *Figure 4* (progressions of other parameters are provided in Figures S1-S5, and detailed values in Tables S2,S3). Both VC and %VC decreased to slightly below 0.8 of their preoperative values at 1 month postoperatively, then gradually recovered, reaching approximately 0.9 of their preoperative values at 12 months postoperatively. Similar trends were observed when analyzed separately for the U and L groups.

Postoperative changes in DCR results

The ratios of preoperative values for maximum and minimum projected lung areas at 1, 3, 6, and 12 months postoperatively are shown in Table S4, and those for excursion of the diaphragm in Table S5.

Projected lung areas (max)

On the affected side, the maximum projected lung area decreased to slightly below 0.7 of the preoperative value at 1 month postoperatively in both U and L groups, then gradually increased over time, recovering to approximately 0.79 of the preoperative values at 12 months postoperatively. The unaffected side maintained values above 1.0 throughout the year in both groups (*Figure 5A*).

Projected lung areas (min)

On the affected side in the U group, the minimum projected lung area recovered gradually from 1 to 6 months postoperatively, reaching 0.79 of the preoperative value at 12 months. The unaffected side maintained values in the 0.9 range compared to the preoperative level in both groups (*Figure 5B*).

Excursion of the diaphragm

On the affected side in the U group, excursion of diaphragm decreased to 0.72 of the preoperative value at 1 month postoperatively and subsequently recovered to 0.94. For the affected side in the L group, it fluctuated within the range of 0.90–0.99 of the preoperative value. On the unaffected side, both groups exceeded the preoperative values, with the U group moving in the range of approximately 1.1 times and the L group around 1.3 times the preoperative value (*Figure 5C*).

Correlation between pulmonary function test results and DCR results

Main results regarding the correlation between the postoperative pulmonary function test results and diaphragmatic contraction ratio metrics at 1, 3, 6, and

Table 1 Demographic data and preoperative pulmonary functions

Variable	Overall (n=65)	Group U (n=44)	Group L (n=21)	P value
Age (years)	72.0±7.6 (50–83)	72.0±7.5 (50–83)	72.1±7.7 (55–82)	0.77
Sex				0.77
Male	47 [72]	31 [70]	16 [76]	
Female	18 [23]	13 [30]	5 [24]	
BMI (kg/m^2)	22.9±2.45 (18.0–29.0)	22.7±2.53 (18.0–29.0)	23.4±2.23 (18.8–27.6)	0.24
17.00–18.49	1 [2]	1 [2]	0 [0]	0.54
18.50–24.99	51 [78]	36 [82]	15 [71]	
25.00–29.99	13 [20]	7 [16]	6 [29]	
Procedure				0.79
Right				
RUL	27 [42]	27 [61]		
RLL	12 [18]		12 [57]	
Left				
LUL	17 [26]	17 [39]		
LLL	9 [14]		9 [43]	
Pathological staging				0.08
0	1 [2]	1 [2]	0 [0]	
IA1	10 [15]	9 [20]	1 [5]	
IA2	21 [32]	12 [27]	9 [43]	
IA3	7 [11]	2 [5]	5 [24]	
IB	10 [15]	8 [18]	2 [10]	
IIA	2 [3]	2 [5]	0 [0]	
IIB	6 [9]	3 [7]	3 [14]	
IIIA	8 [12]	7 [16]	1 [5]	
Approach				0.74
VATS	52 [80]	36 [82]	16 [76]	
Open	13 [20]	8 [18]	5 [24]	
Respiratory comorbidity				0.52
COPD	11 [17]	7 [16]	4 [19]	
IPF	2 [3]	2 [5]	0 [0]	
Others	2 [3]	2 [5]	0 [0]	
Complications 30-day				0.59
Pneumonia	3 [5]	2 [5]	1 [5]	
Pleuritis	5 [8]	1 [2]	4 [19]	
Prolonged air leakage	2 [3]	2 [5]	0 [0]	
Atelectasis	4 [6]	3 [7]	1 [5]	
Acute exacerbation of interstitial pneumonia	1 [2]	1 [2]	1 [5]	
Chylothorax	1 [2]	1 [2]	0 [0]	
Atrial fibrillation	9 [14]	7 [16]	2 [10]	
Others	4 [6]	2 [5]	2 [10]	

Table 1 (*continued*)

Table 1 *(continued)*

Variable	Overall (n=65)	Group U (n=44)	Group L (n=21)	P value
Complications 90-day				>0.99
Pneumonia	1 [2]	1 [2]	0 [0]	
Others	1 [2]	1 [2]	0 [0]	
Pulmonary function test values				
VC (L)	3.47±0.82 (1.96–6.46)	3.50±0.86 (2.17–6.46)	3.41±0.75 (1.96–5.21)	0.64
%VC	106.0±11.7 (76.8–140.3)	106.6±10.5 (83.3–140.3)	104.5±14.1 (76.8–137.2)	0.37
FVC (L)	3.41±0.79 (1.88–6.25)	3.44±0.83 (2.12–6.25)	3.35±0.72 (1.88–4.96)	0.58
%FVC	108.4±11.7 (78.0–139.2)	109.2±10.5 (85.1–139.2)	106.6±13.9 (78.0–138.8)	0.32
FEV1 (L)	2.37±0.62 (1.43–4.60)	2.39± 0.68 (1.43–4.60)	2.34± 0.48 (1.50–3.19)	0.86
%FEV1	94.8±16.1 (51.2–128.9)	95.8±17.1 (51.2–125.5)	92.7±13.9 (70.4–128.9)	0.37
FEV1%	69.9±8.80 (38.0–86.2)	69.6±9.00 (38.0–86.2)	70.5±8.53 (46.4–79.7)	0.50
DL_{CO} (mL/min/mmHg)	16.2±4.50 (6.80–27.5)	16.5±4.83 (6.80–27.5)	15.5±3.74 (6.95–22.8)	0.49
$\%DL_{CO}$	103.3±26.5 (37.1–154.7)	105.3±28.7 (37.1–154.7)	99.0±21.1 (50.9–131.8)	0.37
DL_{CO}/V_A (mL/min/mmHg/L)	3.95±1.09 (1.66–6.29)	3.96±1.10 (1.69–6.29)	3.91±1.09 (1.66–6.15)	0.98
$\%DL_{CO}/V_A$	88.4±21.5 (38.3–130.1)	88.3±21.9 (38.3–130.1)	88.6±24.3 (40.1–125.5)	0.82

Data are presented as mean ± SD (range) or n [%]. U, upper; L, lower; BMI, body mass index; RUL, right upper lobectomy; RLL, right lower lobectomy; LUL, left upper lobectomy; LLL, left lower lobectomy; VATS, video-assisted thoracoscopic surgery; COPD, chronic obstructive pulmonary disease; IPF, idiopathic pulmonary fibrosis; VC, vital capacity; %VC, percent vital capacity; FVC, forced vital capacity; %FVC, percent forced vital capacity; FEV1, forced expiratory volume in 1 second; %FEV1, percent predicted FEV1; $\%DL_{CO}$, percent diffusing capacity of the lungs for carbon monoxide; FEV1%, forced expiratory volume percent in 1 second divided by forced vital capacity; DL_{CO}, diffusing capacity of the lungs for carbon monoxide; DL_{CO}/V_A, diffusing capacity divided by the alveolar volume; $\%DL_{CO}/V_A$, percent diffusing capacity divided by the alveolar volume.

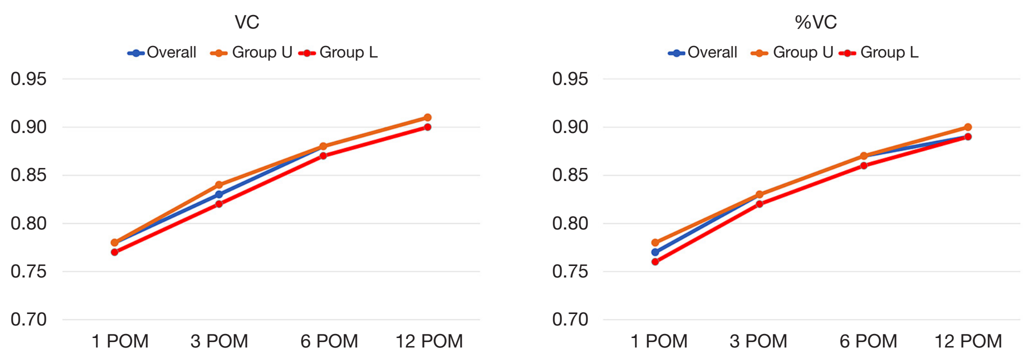

Figure 4 Postoperative changes in the VC and %VC values (ratio to preoperative). U, upper; L, lower; VC, vital capacity; POM, postoperative month.

12 months postoperatively are presented in Table S6. Several parameters showed correlation coefficients exceeding 0.4, indicating strong associations. Detailed correlation data for all the parameters are provided in Tables S7-S9.

In both U and L groups, significant positive correlations were observed between the maximum projected lung area on the affected side and VC and %VC throughout the first postoperative year. The correlation coefficients remained relatively high at 0.6–0.7 in the U group and around 0.4 in the L group.

Regarding excursion of the diaphragm, significant positive correlations with VC, %VC, FVC, and %FVC were observed on the affected side in the U group. In the L group, no significant correlations were found between the

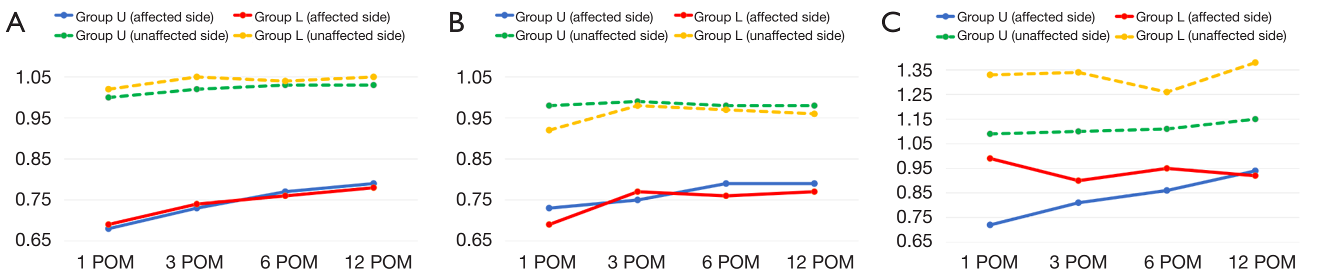

Figure 5 Postoperative changes in the dynamic chest radiography (ratio to preoperative). (A) Projected lung areas (max). (B) Projected lung areas (min). (C) Excursion of diaphragm. U, upper; L, lower; POM, postoperative month.

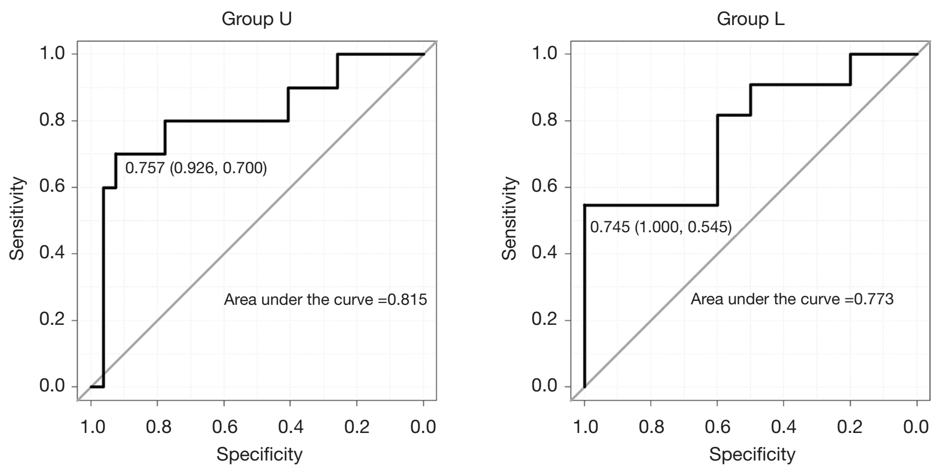

Figure 6 Receiver operating characteristic curve for the prediction of vital capacity at 12 months postoperatively using the maximum projected lung field at 1 month postoperatively in groups U and L. U, upper; L, lower.

excursion of the diaphragm and pulmonary function test results on either the affected or unaffected sides.

Prediction of postoperative VC using maximum projected lung area on the affected side

An ROC curve analysis was performed to evaluate the relationship between the maximum projected lung area on the affected side at 1 month postoperatively and recovery of VC at 12 months postoperatively (using preoperative values of 0.97 for the U group and 0.90 for the L group as references); the results were as follows: the U group had an AUC of 0.815 with a 95% CI of 0.636–0.994, and the L group had an AUC of 0.773 with a 95% CI of 0.564–0.982. The cutoff values were 0.757 and 0.745 for the U and L groups, respectively, with sensitivities of 0.700 and 0.545, and specificities of 0.926 and 1.000, respectively (*Figure 6*).

Discussion

In the current study, we observed the progression of diaphragm contraction ratio test results—namely maximum and minimum projected lung areas and excursion of diaphragm, from preoperative to 1 year postoperatively in patients undergoing lobectomy for primary lung cancer. In addition, we clarified the correlation between these parameters and pulmonary function test outcomes stratified by surgical procedure. Previous reports have addressed the factors affecting pulmonary function recovery and assessment, including the importance of smoking cessation and variables related to postoperative recovery (36,37). In our study the maximum projected lung area on the affected side showed a significant correlation with the recovery of pulmonary function, as represented by the VC, particularly in the upper lobectomy group. Furthermore, irrespective of the surgical procedure, the maximum projected lung area at 1 month postoperatively significantly correlated with VC recovery at 1 year postoperatively. DCR, a recently developed technology, enabled dynamic analysis of various structures within the thoracic cavity. While various reports exist, most have focused on healthy individuals or patients with diseases, with very few reports in the context of perioperative thoracic surgery (20-32). Observing the impact of surgery such as lobectomy on various DCR parameters and reflecting this in treatment and perioperative management to benefit patients is crucial. This study reports on the progression of DCR outcomes in patients undergoing lobectomy, observing the significant factors correlated with respiratory function, thereby providing significant insights.

Our findings are consistent with previous studies on preoperative conditions. Specifically, DCR parameters indicated larger maximum and minimum projected lung area s on the right side and greater excursion of diaphragm on the left (23-25). Previous studies have reported that the chest radiography-measured projected lung areas correlate with pulmonary function test outcomes (38-41). Similarly, projected lung area s in DCR correlate with pulmonary function test outcomes in healthy individuals. Our findings revealed a significant positive correlation between the projected lung area on the affected side, as measured by DCR, and the recovery of pulmonary function following lobectomy. Although both the U and L groups showed similar trends, the correlation coefficients were lower in the L group, with no correlation observed beyond 6 months postoperatively. This discrepancy may be attributed to the difference between the projected lung area and actual lung volume, with 40% of the lung being obscured by the heart shadow and diaphragm on chest radiographs, potentially affecting the lower lobes more (42). Thus, changes in the projected lung area in the U group might accurately reflect changes in lung volume over time, unlike in the L group, where overlap with mediastinal and diaphragmatic structures could obscure correlations after 6 months.

Previous studies have utilized ultrasound to assess postoperative diaphragmatic mobility (19). Similar to the findings of our study, these studies suggest that the impact on diaphragmatic motion may differ between upper lobectomy and lower lobectomy. Although ultrasound is a convenient diagnostic tool, its observations are limited to intercostal views. In contrast, DCR has potential advantages, including the ability to simultaneously evaluate both sides of the chest, provide a comprehensive view of the entire thoracic cavity, and offer higher resolution for more detailed assessments. Another previous study has evaluated postoperative diaphragm mobility using magnetic resonance imaging (MRI) (43). Their findings, which are consistent with our current observations, indicated that diaphragm mobility on the operative side decreased after surgery and gradually recovered over time, while mobility on the contralateral side increased compared to the preoperative levels. Furthermore, they reported a more severe reduction in mobility following left upper lobectomy, which aligns with our observations in the U group. However, that study did not analyze the correlation between lung function recovery and changes in diaphragm mobility. In our current study, postoperative excursion of diaphragm on the affected side of the U group decreased to 0.72 of the preoperative value before recovering, showing a significant positive correlation with pulmonary function test results. The L group maintained a ratio of approximately 0.9, suggesting that post-lobectomy diaphragmatic motion and its impact on postoperative pulmonary function recovery may vary according to the surgical procedure. Possible reasons for this include differences in the pleural effusion volume due to the resected lobe and manipulation around the phrenic nerve during hilar processing (although no cases of phrenic nerve paralysis were observed). Regardless of the surgical procedure, the diaphragmatic motion on the unaffected side slightly exceeded preoperative levels, suggesting a compensatory increase in contralateral diaphragmatic motion.

Multiple correlations were observed between postoperative DCR results and pulmonary function test outcomes, suggesting that DCR performed in a seated position and during quiet breathing may offer a less burdensome alternative to conventional pulmonary function tests, especially in the early postoperative period when patients may still be affected by pain. Additionally, its lower radiation exposure and smaller equipment size compared to those of CT scan or MRI suggest its potential utility as an alternative for postoperative pulmonary function evaluation.

As previously mentioned, both the U and L groups showed a significant correlation between the maximum projected lung area and pulmonary function test results, especially VC in the early postoperative period. ROC curve analysis evaluating the degree of VC recovery at 12 months postoperatively, based on the maximum projected lung area at 1 month postoperatively, indicated that cutoff values for the maximum projected lung area could be determined for both groups, with high AUC values. This suggests that measuring the maximum projected lung area 1 month postoperatively in patients undergoing lobectomy could predict VC recovery at 12 months postoperatively. In our patient group, complications that could affect DCR results or postoperative pulmonary function were minimal, indicating that within a range of linear recovery, changes in the projected lung area measured by DCR reflect respiratory function at each time point and long-term postoperative pulmonary function. Using the recovery rate of the maximum projected lung area as a recovery indicator could help evaluate the effectiveness of postoperative care and rehabilitation and adjust interventions as needed, potentially accelerating patient recovery and providing more effective treatment. Preferably, a model that uses preoperative DCR measurements rather than early postoperative measurements would be ideal for predicting postoperative pulmonary function trends. Further research requires the continuous accumulation of cases and data collection.

However, our study had some limitations. First, it was a single-center study with a limited number of patients. Moreover, 13 patients dropped out before sufficient data could be obtained (e.g., only preoperative examinations were performed), primarily due to patient-related reasons. Consequently, the number of patients with comorbidities, such as COPD or interstitial pneumonia, or those with postoperative complications was limited, and their impact was not sufficiently examined. Moreover, the amount of pleural effusion can affect diaphragmatic motion to some extent. However, in DCR, significant pleural effusion that obscures the diaphragmatic line makes evaluation difficult. Therefore, patients with large amounts of pleural effusion were excluded from our study. Therefore, the effect of pleural effusion volume on diaphragmatic motion has not been fully evaluated. However, we hypothesize that a reproducible study is possible in patients who do not experience significant postoperative complications.

Similar to previous reports (19), our findings revealed differences based on the type of surgical procedure performed (upper *vs.* lower lobectomy). Ideally, the analysis should have been divided into upper/lower and left/right categories; however, this approach was not implemented in this study owing to the limited number of patients.

Additionally, DCR imaging was performed using automated vocal respiratory instructions, and it remains unclear whether breathing was consistent at each measurement. Postoperative pain may contribute to individual variations, especially during the early postoperative period. However, these factors are likely to be relevant for other imaging examinations, such as chest radiographs and CT scans, as well as pulmonary function tests.

Conclusions

This study revealed that irrespective of the surgical procedure performed, a correlation exists between the projected lung area obtained using DCR and recovery of pulmonary function. In addition, a similar correlation was observed in upper lobectomy between excursion of diaphragm and recovery of pulmonary function. A simple and less burdensome DCR could potentially serve as an alternative to traditional pulmonary function tests, especially for patients in the early postoperative period. The findings suggest the potential of using the maximum projected lung area measured at 1 month postoperatively to predict VC recovery at 12 months. Therefore, DCR can be used as a prognostic marker for future pulmonary function recovery during the early postoperative period.

Acknowledgments

None.

Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://qims.amegroups.com/article/view/10.21037/qims-24-1714/rc

Funding: None.

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-24-1714/coif). J.H. received a research grant from Konica Minolta Inc. The other 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. This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Ethics Committee of Shiga University of Medical Science (No. CRB 5180008; October 10, 2017). Written informed consent was obtained from all patients using a descriptive informed consent form.

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Cite this article as: Hayashi K, Shiratori T, Ueda K, Okamoto K, Kataoka Y, Kawaguchi Y, Ohshio Y, Hanaoka J. Dynamic chest radiography in post-lobectomy recovery: a novel approach to evaluating pulmonary function and thoracic structures in patients with primary lung cancer. Quant Imaging Med Surg 2025;15(3):2232-2245. doi: 10.21037/qims-24-1714