

Morphological and functional reserves of the right middle lobe: radiological analysis of changes after right lower lobectomy in healthy individuals

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33 **Abbreviations**

34 CT = computed tomography

35 RU lobe = right upper lobe

36 RM lobe = right middle lobe

37 RL lobe = right lower lobe

38 RL lobectomy = right lower lobectomy

39 ELV = effective lung volume

40 LAA = low attenuation area

41 FVC = forced vital capacity

42 FEV₁ = forced expiratory volume in one second

43 DL_{CO} = diffusing capacity of lung for carbon monoxide

44

45 **Central Picture Legend**

46 The middle lobe shows expansion and functional compensation after right lower
47 lobectomy.

48 **Central Message**

49 The right middle lobe contributes largely to expansion and functional compensation
50 after right lower lobectomy with preservation of its structural complexity.

51 **Perspective Statement**

52 Expansion and functional compensation of the remaining lung after pulmonary
53 resection are heterogeneous. Following right lower lobectomy, the right middle lobe
54 demonstrates morphological and functional reserves, despite its small size. Better
55 understanding of such heterogeneous changes would lead to an improvement of
56 methods to predict postoperative function.

57 **Abstract**

58 Objectives

59 Remaining lung tissue after pulmonary resection can expand without decline in
60 structural complexity and compensate for functional loss, showing morphological and
61 functional reserves. However, the distribution of these reserves is unknown. This study
62 examined the heterogeneity of morphological and functional reserves of the remaining
63 lung tissue.

64 Methods

65 We retrospectively analyzed 53 donors who underwent right lower lobectomy for
66 living-donor lobar lung transplantation. We examined morphometric changes in
67 computed tomography images from 3 to 12 months after lobectomy. We assessed lung
68 volume and structural complexity expressed as the fractal dimension. We also assessed
69 effective lung volume (the volume of the lung with intermediate density) and
70 volumetric fluctuation during respiration. Changes were compared between the right
71 upper lobe, middle lobe, and left lung.

72 Results

73 The expansion of lung tissue was greater in the middle lobe ($130.9 \pm 19.7\%$) than in the
74 upper lobe ($109.7 \pm 9.2\%$, $P < 0.001$). The fractal dimension declined in the upper lobe

75 (P < 0.001) but was maintained in the middle lobe (P = 0.39). The increase in effective
76 lung volume was larger in the middle lobe (97.2 ± 73.5 ml) than in the upper lobe (62.7
77 ± 87.1 ml, P < 0.001) but not significantly different from that of the left lung ($55.8 \pm$
78 186.3 ml, P = 0.052). A similar pattern was seen in respiratory fluctuation.

79 Conclusions

80 Morphological and functional changes in lung tissue remaining after pulmonary
81 resection were heterogeneous. The right middle lobe demonstrated morphological and
82 functional reserves after right lower lobectomy.

83 (250 words)

84 **Graphical abstract legend**

85 Among heterogeneous changes in the remaining lung tissue after right lower lobectomy,
86 the RM lobe demonstrates great morphological and functional reserves, compared to the
87 RU lobe.

88 CT, computed tomography; RU lobe, right upper lobe; RM lobe, right middle lobe.

Pulmonary resection is a widely utilized therapeutic option for lung diseases¹. Expansion of the remaining lung tissue is a major compensatory response after resection^{2, 3}. However, postoperative changes in the pulmonary microstructure have not been fully elucidated. Our group previously reported that the structural complexity of the ipsilateral remaining lung was preserved after lower lobectomy despite the increase in volume⁴, which suggests a “morphological reserve” of the remaining lung tissue.

Patients who undergo pulmonary resection gradually recover pulmonary function^{5, 6}. Function after anatomical resection was reported to exceed predicted values^{5, 7}, which are calculated on the assumption that the function of the remaining lungs does not change between before and after resection. These findings suggest that the remaining lungs could also have functional reserves.

Remaining lung tissue expanded heterogeneously after resection in animal models⁸. Based on this finding, morphological reserves in the remaining lung tissue may be distributed heterogeneously. Moreover, because pulmonary function is associated with lung volume^{9, 10}, functional reserves may also be heterogeneous. However, interlobar heterogeneity in morphological and functional reserves has not been studied in previous studies, including those from our group^{4, 6}.

In this study, we hypothesized that morphological and functional reserves are

heterogeneous in the remaining lung tissue. We retrospectively analyzed computed tomography (CT) images of the remaining lung tissue after right lower lobectomy (RL lobectomy) in healthy adults who donated their lobes in living-donor lobar lung transplantation.

Methods

This retrospective observational study was conducted in a single center. The Ethics Committee of Kyoto University Hospital approved the protocol. The need for written informed consent was waived because of the retrospective nature of this study.

We searched the institutional database at Kyoto University Hospital for donors who underwent RL lobectomy for living-donor lobar lung transplantation between January 2011 and December 2017. The donor selection criteria⁶ are listed in Table 1. Patients with chronic obstructive lung disease were not included in donors. We mainly analyzed regional changes in CT morphometrics from 3 to 12 months after RL lobectomy.

CT acquisition

CT images were obtained during deep inspiratory and expiratory breath-holding using multidetector CT scanners before and 3 and 12 months after lobectomy. We used three

scanners (Toshiba Medical Systems, Tochigi, Japan): Aquilion 64 from January 2011 to January 2016, Aquilion ONE from August 2015 to January 2019, and Aquilion PRIME from February 2016 to April 2018. The scanning parameters were the same throughout the study period: 0.5-mm collimation, field of view of 320–381 mm, a gantry rotation time of 500 ms, and automatic exposure control at 120 kVp. No intravenous contrast medium was administered. Images with a slice thickness of 1 mm were reconstructed using a standard lung algorithm (FC51).

Three-dimensional CT volumetry

CT data were imported into a workstation SYNAPSE VINCENT (FUJIFILM Medical, Tokyo, Japan) for segmentation and three-dimensional CT volumetry. The airway and thoracic cage were removed from images. Areas less than -250 Hounsfield Units (HU) were extracted as lung fields. Interlobar lines were drawn semi-automatically. All lines were checked in multiplanar reconstruction images and manually corrected paying careful attention to interlobar fissures (even when they were incomplete) and peripheral bronchi and vessels. Volumes of the right upper (RU), right middle (RM), and right lower (RL) lobe and the left lung were measured automatically. The diaphragmatic surface of the lung was evaluated using three-dimensional reconstructed images,

regardless of whether there was intervening pleural effusion.

Effective lung volume (ELV) was defined as volume of the lung area with a CT density of -950 to -600 HU on inspiratory CT¹¹. To assess respiratory fluctuation in lung volume, the difference in CT volumes between deep inspiration and expiration was calculated.

Fractal analysis

Postoperative inspiratory CT images were analyzed using custom-made software. We calculated the D value of each lung region in a fractal analysis of the low attenuation area (LAA) cluster. The D value reflects the fractal dimension of the terminal air space geometry, indicating the structural complexity of the lung¹². As previously reported, the cumulative frequency distribution of the LAA cluster Y, which is the number of clusters larger than the size of a given cluster X, follows a power law of $Y = K \times X^{-D}$, where K is a constant¹². The exponent, D, can be calculated as the slope of the straight line on log-log plots in a linear regression^{12, 13}. In this study, D was calculated for each axial image. The average of all these values were used to calculate D for a region. We determined the threshold of LAA as the 25th percentile of a histogram of CT densities in the lung field. This D value, referred to as D'25, was reported to be robust against

changes in the lung volume and to have the potential to detect structural changes in patients with chronic obstructive pulmonary disease more sensitively than the conventional D value and fraction of LAA¹³.

Prediction of postoperative pulmonary function

Pulmonary function tests, including forced vital capacity (FVC), forced expiratory volume in one second (FEV₁), and diffusing capacity of lung for carbon monoxide (DL_{CO}), were performed before and 3 and 12 months after lobectomy. We predicted postoperative FVC, FEV₁, and DL_{CO} using two methods. In the segment counting method, predicted values (FVC, FEV₁, and DL_{CO}) were calculated using the following equation: predicted value = preoperative value × 14/19. In the CT volumetric method, which is a modified version of a previously described method⁷, predicted values were calculated using the following equation: predicted value = preoperative value × (1-[ELV in RL lobe]/[ELV in whole lungs]).

Statistical analysis

Statistical analysis was performed using JMP® Pro 14.0.0 software (SAS Institute Inc., Cary, NC). Expansion of the lung is expressed as a ratio of lung volume. Changes in

D'25, ELV, and respiratory fluctuation are expressed as differences. Continuous variables are expressed as mean $\pm$ standard deviation. Comparisons of continuous variables were analyzed using a paired *t*-test. Differences were considered significant at values of $P < 0.05$.

Results

Seventy-five donors underwent RL lobectomy during the study period. Among them, 12 donors lacked CT images following the appropriate protocol. Donors with air in the pleural space ($n = 9$) and ground glass opacity in the lung area ($n = 1$) on CT images obtained 3 months after lobectomy were excluded. Therefore, postoperative changes in 53 donors were analyzed. Preoperative characteristics of the donors are shown in Table 2.

Postoperative complications occurred in nine donors, including pneumothorax ($n = 3$), pleural effusion ($n = 3$), hemothorax ($n = 1$), chylothorax ($n = 1$), and a residual foreign body that required re-thoracotomy ($n = 1$). These complications resolved within 3 months of lobectomy. No donors required thoracentesis due to pleural effusion from 3 to 12 months after lobectomy.

Postoperative pulmonary function

Predicted and postoperatively measured functions are described in Table 3. FVC, FEV₁, and DL_{CO} at 12 months were significantly greater than those at 3 months after lobectomy ($P < 0.001$) and those predicted using the two methods ($P < 0.001$).

Gross change in the right lung

Change in a representative case is shown in Figure 1. Before resection, the RM lobe lay in the ventral portion of the lower hemithorax, with little or no contact with the diaphragm. After RL lobectomy, the remaining right lung deformed and expanded to compensate for the loss of the RL lobe. The RM lobe occupied most or all of the diaphragmatic surface of the remaining right lung.

Changes in CT morphometrics from 3 to 12 months after lobectomy

Morphometric data from CT images are shown in Table 4. Expiratory CT before and three months after lobectomy was not obtained in one donor. Lung volume, ELV, and respiratory fluctuation increased from 3 to 12 months after lobectomy in the RU lobe, RM lobe, and left lung. D'25 decreased significantly in the RU lobe but was maintained in the RM lobe.

Changes in the morphometrics from 3 to 12 months after lobectomy were compared between regions and are shown in Figure 2. Expansion was greater in the RM lobe ($130.9 \pm 19.7\%$) than in the RU lobe ($109.7 \pm 9.2\%$) ($P < 0.001$) (Figure 2A). The decline in D'25 was greater in the RU lobe (-0.08 ± 0.11) than in the RM lobe (-0.02 ± 0.15) ($P < 0.001$) (Figure 2B). The increase in ELV was greater in the RM lobe (97.2 ± 73.5 ml) than in the RU lobe (62.7 ± 87.1 ml) ($P < 0.001$). There was no significant difference in changes in ELV between the RM lobe and left lung (55.8 ± 186.3 ml) ($P = 0.052$) (Figure 2C). The increase in respiratory fluctuation was greater in the RM lobe (148.2 ± 107.2 ml) than in the RU lobe (95.2 ± 144.2 ml) ($P < 0.001$). There was no significant difference in change in respiratory fluctuation between the RM lobe and left lung (105.5 ± 331.6 ml) ($P = 0.27$) (Figure 2D).

Volumetric changes from before to 12 months after lobectomy

Changes in volume, ELV, and respiratory fluctuation from before to 12 months after lobectomy showed similar tendencies as those observed from 3 to 12 months after lobectomy (Table 4). Expansion of the RM lobe ($192.6 \pm 48.3\%$) was significantly greater than that of the RU lobe ($138.5 \pm 21.2\%$) ($P < 0.001$). The increase in ELV was greater in the RM lobe (252.1 ± 108.7 ml) than in the RU lobe (191.2 ± 104.6 ml) and

left lung (121.2 ± 179.1 ml) ($P < 0.001$). The increase in respiratory fluctuation was greater in the RM lobe (291.5 ± 145.7 ml) than in the RU lobe (166.1 ± 182.5 ml) ($P < 0.001$) but was not significantly different from that in the left lung (319.3 ± 392.7 ml) ($P = 0.58$).

Discussion

In this study, we radiologically analyzed regional changes in remaining lung tissue after RL lobectomy in healthy adults. Regarding heterogeneous changes in the remaining lung tissue, the RM lobe demonstrated great morphological and functional reserves. These specific features of the RM lobe have not been previously reported.

The RM lobe demonstrated morphological reserves after RL lobectomy. The RM lobe greatly expanded without a significant decline in structural complexity, unlike the RU lobe. We previously reported that the structural complexity of the ipsilateral remaining lung was maintained in donors after right or left lower lobectomy⁴. The present study, focusing on RL lobectomy cases, revealed that a large part of the morphological reserves of the remaining right lung was derived from the RM lobe, although the size of the RM lobe was small preoperatively.

The RM lobe also demonstrated great functional reserves. Pulmonary function tests

revealed that remaining lung tissue compensated for the functional loss of the RL lobe. Among regions of the remaining lungs, gains in ELV and respiratory fluctuation were greater in the RM lobe than in the RU lobe and not significantly inferior to those in the left lung. These results strongly suggest that the RM lobe contributed largely to the postoperative functional compensation.

Reserves of the RM lobe could be associated with its position relative to the diaphragm. Preoperatively, the RM lobe had limited or no contact with the diaphragm. Inflation and ventilation of the RM lobe were modest, compared to those of the RU and RL lobes. After RL lobectomy, however, the RM lobe obtained broader contact with the diaphragm and showed greater amplification of inflation and ventilation than the RU lobe. A similar heterogeneity was found in previous studies^{8, 14}. In the first study using four-dimensional CT in healthy adults, the lower lobes contributed to ventilation more than the upper and middle lobes¹⁴. The authors attributed the heterogeneity to the motion of the diaphragm, which is the predominant driver of lung inflation. In the other study focusing on changes after resection in a canine model, the expansion after extensive pulmonary resection was larger in the lobe next to the diaphragm than that in the other lobes⁸. These two studies highlight the effect of the diaphragm on heterogeneity in preoperative and postoperative behavior of the lung. Based on these

studies, our results can be interpreted as follows: preoperatively, the RL lobe could interfere with inflation and ventilation of the RM lobe by limiting its contact with the diaphragm; removal of the RL lobe could facilitate access of the RM lobe to the diaphragm, enhancing inflation and ventilation of the RM lobe. Although the mechanisms of acquiring and utilizing the reserve are of great interest, they are beyond the scope of this study. Postoperative unfolding of alveolar septa⁸ could be associated with the reserve. Other processes, such as the new growth of alveolar tissue, which was observed after pneumonectomy¹⁵, might be also involved. Further studies would be required to assess this issue.

When evaluating the heterogeneity of postoperative changes, there are two advantages in focusing on donors who underwent RL lobectomy. First, all subjects were healthy adults with no visible abnormalities on CT. Lung cancer is the most common disease that requires pulmonary resection¹. However, emphysema and/or pulmonary fibrosis are sometimes seen in patients with lung cancer, making these individuals poor candidates for assessing the effects of resection on lung tissue. Second, the minor fissure in the right lung, even if incomplete, helps define the interlobar line to separate the RU and RM lobes. Left lower lobectomy has also been performed in donors; however, this does not allow the evaluation of the heterogeneity of changes in our methods owing to

difficulty in the division of the left upper lobe into the upper division and lingula because the fissure between these two regions is usually absent¹⁶.

Our findings obtained from living donors could help predict postoperative behavior of the lungs in other situations. In the field of cadaveric transplantation, bilateral lung transplantation, in which the RL lobe is not utilized due to lung injury, may induce similar changes in the recipient. A more common example is RL lobectomy for lung cancer in patients without pulmonary comorbidities. We estimate that this population accounts for a certain proportion of surgical patients, considering that the frequency of never smokers in patients undergoing resection for lung cancer is increasing^{17, 18}. On the other hand, it is unknown whether lungs in patients with emphysema or pulmonary fibrosis experience similar changes after lobectomy. Further studies are warranted to assess this issue.

The heterogeneity in changes may have an effect on the prediction of postoperative pulmonary function. As our data demonstrated, postoperative pulmonary function often exceeds predicted values^{5, 7}. One reason for this discrepancy is that the remaining lung tissue compensates for functional loss. The site of resection could influence postoperative functional compensation¹⁹. Heterogeneous change, which we found in this study, may also influence the extent of compensation. Further exploration of the

heterogeneity would provide us better knowledge on postoperative changes, leading to the development of more accurate prediction of postoperative function.

This study has limitations. First, this is a retrospective study with relatively small number of cases. Second, the use of multiple CT scanners may have influenced the results. We additionally examined 32 cases in which the same CT scanner was used at 3 and 12 months after lobectomy. Donor characteristics were almost the same as those of the entire cohort (Supplementary table 1). The results were similar to those obtained from the analysis of 53 cases, except that the CT volumes of the left lung did not increase (Supplementary table 2). Prospective studies are required to exclude the potential effects of using multiple scanners on the results. Third, neither changes immediately after lobectomy nor those in long-term were investigated. We did not compare structural complexity between before and after lobectomy because deformations immediately after RL lobectomy in the remaining lobes, especially in the RM lobe, were so large that they could affect the results of the fractal analysis even without structural alterations. More sophisticated methods are required to assess regional changes in the structural complexity between before and after resection. Regarding long-term changes, because the postoperative follow-up of donors is usually terminated at 1 year after donation, we could not analyze changes over a longer period.

Fourth, postoperative pleural effusion and shift in pulmonary perfusion may have influenced the results. Although the pleural effusion was too small to require thoracentesis, it may have influenced the postoperative changes in the lung, for example, by inducing microatelectasis. Resection can alter pulmonary perfusion by decreasing the vascular bed volume and migration of the lung, modifying regional CT densities. Although these two events occur immediately after resection, the changes in CT morphometrics between 3 and 12 months after lobectomy may have been influenced by a shift in perfusion. In the histogram of CT densities in the lung field, pixels were frequently distributed near the -950 to -600 HU range. Therefore, the ELV, which is the volume of the lung area with a CT density in the abovementioned range, may have been influenced by the change in CT densities because of the shift in perfusion. However, the lung volume, calculated as a volume less than -250 HU, would be less susceptible because few pixels had CT densities near -250 HU. In the fractal analysis, the effect of perfusion on D'25 would be minimal because the threshold density of LAA for D'25 is not fixed (for example, at -950 HU), but it reflects the distribution of CT densities in the region. Fifth, the accuracy of interlobar lines were not tested.

In conclusion, this study revealed that changes in the remaining lung tissue after RL lobectomy were heterogeneous and that the RM lobe demonstrated morphological and

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404

405

Figure legends

FIGURE 1. Three-dimensional reconstructed images showing postoperative gross change. The left lung is removed in the right lateral views. After right lower lobectomy, the right middle lobe greatly expanded and extended its diaphragmatic surface area. Yellow, right upper lobe; blue, right middle lobe; green, right lower lobe; red, left lung.

FIGURE 2. Comparison of morphometric changes from 3 to 12 months after lobectomy between regions. A, expansion was greater in the RM lobe ($130.9 \pm 19.7\%$) than in the RU lobe ($109.7 \pm 9.2\%$) ($P < 0.001$, $n = 53$). B, the decline in structural complexity, expressed as D'25, was greater in the RU lobe (-0.08 ± 0.11) than in the RM lobe (-0.02 ± 0.15) ($P < 0.001$, $n = 53$). C, the increase in ELV was greater in the RM lobe (97.2 ± 73.5 ml) than in the RU lobe (62.7 ± 87.1 ml) ($P < 0.001$, $n = 53$). D, the increase in respiratory fluctuation was greater in the RM lobe (148.2 ± 107.2 ml) than in the RU lobe (95.2 ± 144.2 ml) ($P < 0.001$, $n = 52$). ELV, effective lung volume; RU lobe, right upper lobe; RM lobe, right middle lobe.

Table 1. Criteria for selection of donors in living-donor lobar lung transplantation

Age ≥ 20 and ≤ 60 years
Relatives within the third degree or a spouse of the recipient
ABO blood type identical or compatible to the recipient
No major medical history or active medical problems
No recent viral infections
Non-smoker (current smoker at the offer for donation is required never to smoke after then)
No major abnormalities of the lung on the graft side on CT
FVC and FEV ₁ $\geq 85\%$ of predicted values
Partial pressure of arterial oxygen ≥ 80 Torr
No history of thoracic operations on the graft side
No abnormalities on the electrocardiogram or echocardiogram
Satisfactory psychosocial evaluation
Voluntary donation

CT, computed tomography; FVC, forced vital capacity; FEV₁, forced expiratory volume in one second.

Table 2. Preoperative characteristics of donors

Age (years)	40 ± 11
Sex (male), n (%)	37 (70)
Height (cm)	167.3 ± 7.1
Body mass index (kg/m ²)	23.5 ± 3.0
Smoking history (never/ex/current)	27/25/1
Smoking pack-years of ever smoker	13 ± 8
Pulmonary function test	
FVC (% predicted)	104.2 ± 12.8
FEV ₁ (% predicted)	98.7 ± 11.2
FEV ₁ /FVC (%)	82.6 ± 6.5
DL _{CO} (% predicted)	93.9 ± 12.2

FVC, forced vital capacity; FEV₁, forced expiratory volume in one second; DL_{CO}, diffusing capacity of lung for carbon monoxide.

Table 3. Postoperative pulmonary function

	Predicted value		Measured value	
	Segment	CT	3 months	12 months
	counting	Volumetry		
FVC (L)	3.03 ± 0.54	3.02 ± 0.54	3.07 ± 0.69	3.54 ± 0.72*
FEV ₁ (L)	2.50 ± 0.45	2.49 ± 0.45	2.65 ± 0.55	2.92 ± 0.54*
DL _{CO}	19.09 ± 3.80	19.04 ± 3.85	20.19 ± 4.58	21.82 ± 4.89*
(ml/min/mmHg)				

* P<0.001 compared with predicted values and with the measured value at 3 months after lobectomy. FVC, forced vital capacity; FEV₁, forced expiratory volume in one second; DL_{CO}, diffusing capacity of lung for carbon monoxide; CT, computed tomography.

Table 4. Changes in CT morphometrics

	Before	After lobectomy		P	
	lobectomy ^a	3 months ^b	12 months ^c	a vs. c	b vs. c
Lung volume					
RU lobe (ml)	881.8 ± 203.2	1107.4 ± 263.8	1213.2 ± 299.1	< 0.001	< 0.001
RM lobe (ml)	441.4 ± 103.7	635.0 ± 141.8	824.4 ± 199.7	< 0.001	< 0.001
RL lobe (ml)	1295.2 ± 273.0				
Left lung (ml)	2300.8 ± 450.3	2454.5 ± 447.9	2530.5 ± 453.1	< 0.001	0.032
D'25					
RU lobe		2.15 ± 0.15	2.07 ± 0.18		< 0.001
RM lobe		2.10 ± 0.18	2.08 ± 0.22		0.39
Left lung		2.12 ± 0.18	2.10 ± 0.19		0.27
ELV					
RU lobe (ml)	662.6 ± 162.4	791.1 ± 188.6	853.8 ± 206.0	< 0.001	< 0.001
RM lobe (ml)	310.6 ± 76.7	465.5 ± 102.1	562.7 ± 129.9	< 0.001	< 0.001
RL lobe (ml)	966.3 ± 176.0				
Left lung (ml)	1708.8 ± 311.4	1774.1 ± 316.6	1829.9 ± 301.4	< 0.001	0.034
Respiratory fluctuation					

RU lobe (ml)	347.8 ± 168.7	432.3 ± 223.7	524.9 ± 256.3	< 0.001	< 0.001
RM lobe (ml)	144.7 ± 67.7	289.4 ± 121.7	439.2 ± 166.9	< 0.001	< 0.001
RL lobe (ml)	652.0 ± 249.4				
Left lung (ml)	1055.9 ± 410.1	1288.5 ± 462.8	1388.7 ± 437.6	< 0.001	0.026

CT computed tomography; ELV, effective lung volume; RU lobe, right upper lobe; RM lobe, right middle lobe; RL lobe, right lower lobe.

424 **Video legends**

425 Short video describing the radiological methods of this study.

Supplementary table 1. Preoperative characteristics of donors undergoing CT with the same scanner

Age (years)	39 ± 11
Sex (male), n (%)	24 (75)
Height (cm)	167.7 ± 7.7
Body mass index (kg/m ²)	23.5 ± 2.8
Smoking history (never/ex/current)	16/16/0
Smoking pack-years of ever smoker	12 ± 7
Pulmonary function test	
FVC (% predicted)	104.3 ± 13.7
FEV ₁ (% predicted)	99.4 ± 10.1
FEV ₁ /FVC (%)	83.8 ± 6.0
DL _{CO} (% predicted)	92.8 ± 12.2

FVC, forced vital capacity; FEV₁, forced expiratory volume in one second; DL_{CO}, diffusing capacity of lung for carbon monoxide.

Supplementary table 2. Morphometric changes in donors undergoing CT using the same scanner

	3 months	12 months	P
Lung volume			
RU lobe (ml)	1127.6 ± 290.4	1211.3 ± 326.0	< 0.001
RM lobe (ml)	646.6 ± 153.1	824.4 ± 206.9	< 0.001
Left lung (ml)	2511.5 ± 463.5	2521.0 ± 450.4	0.82
D'25			
RU lobe	2.18 ± 0.17	2.11 ± 0.18	< 0.001
RM lobe	2.15 ± 0.19	2.15 ± 0.24	0.95
Left lung	2.18 ± 0.16	2.16 ± 0.19	0.20
ELV			
RU lobe (ml)	776.9 ± 198.3	802.6 ± 197.3	0.049
RM lobe (ml)	460.6 ± 113.1	530.3 ± 123.5	< 0.001
Left lung (ml)	1763.0 ± 309.3	1738.9 ± 261.7	0.33
Respiratory fluctuation			
RU lobe (ml)	465.6 ± 243.6	525.7 ± 281.5	0.020
RM lobe (ml)	301.7 ± 118.6	434.0 ± 160.1	< 0.001

Left lung (ml)	1353.4 ± 453.8	1380.0 ± 443.3	0.62
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CT computed tomography; ELV, effective lung volume; RU lobe, right upper lobe;

RM lobe, right middle lobe.

427

428

Central picture

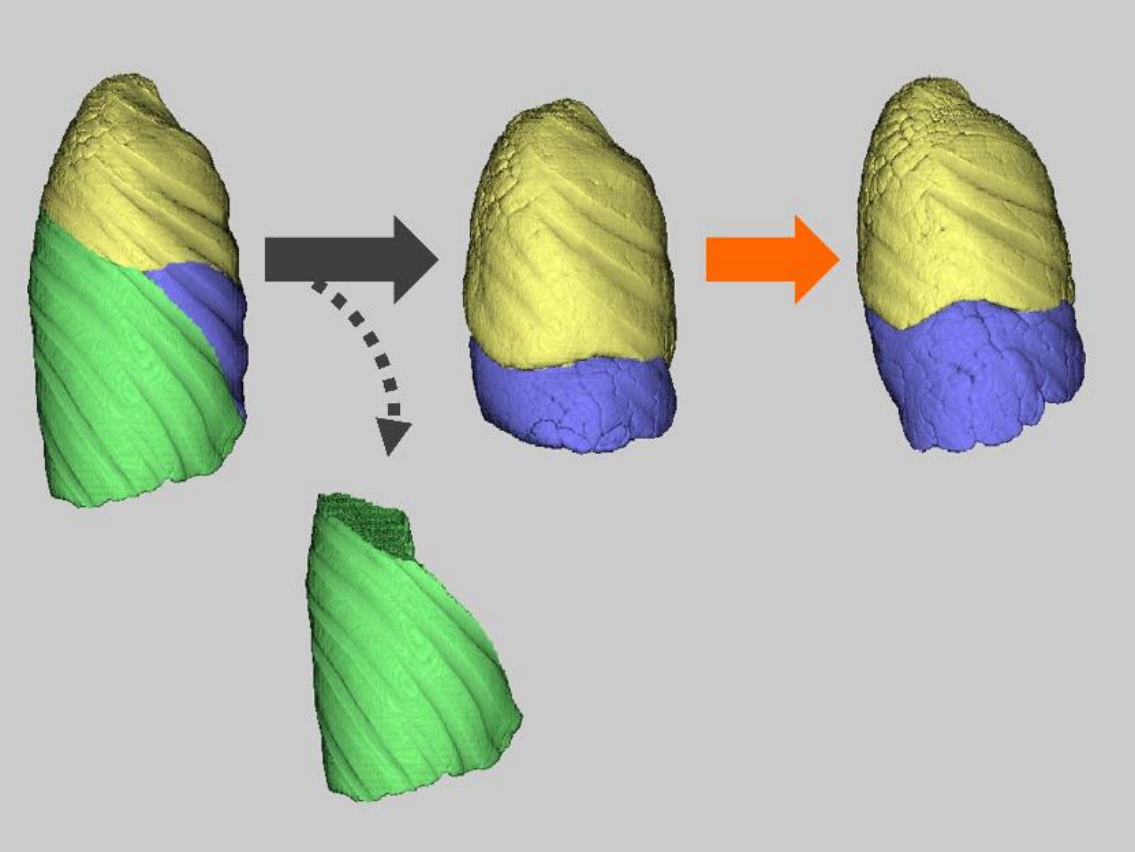


Figure 1

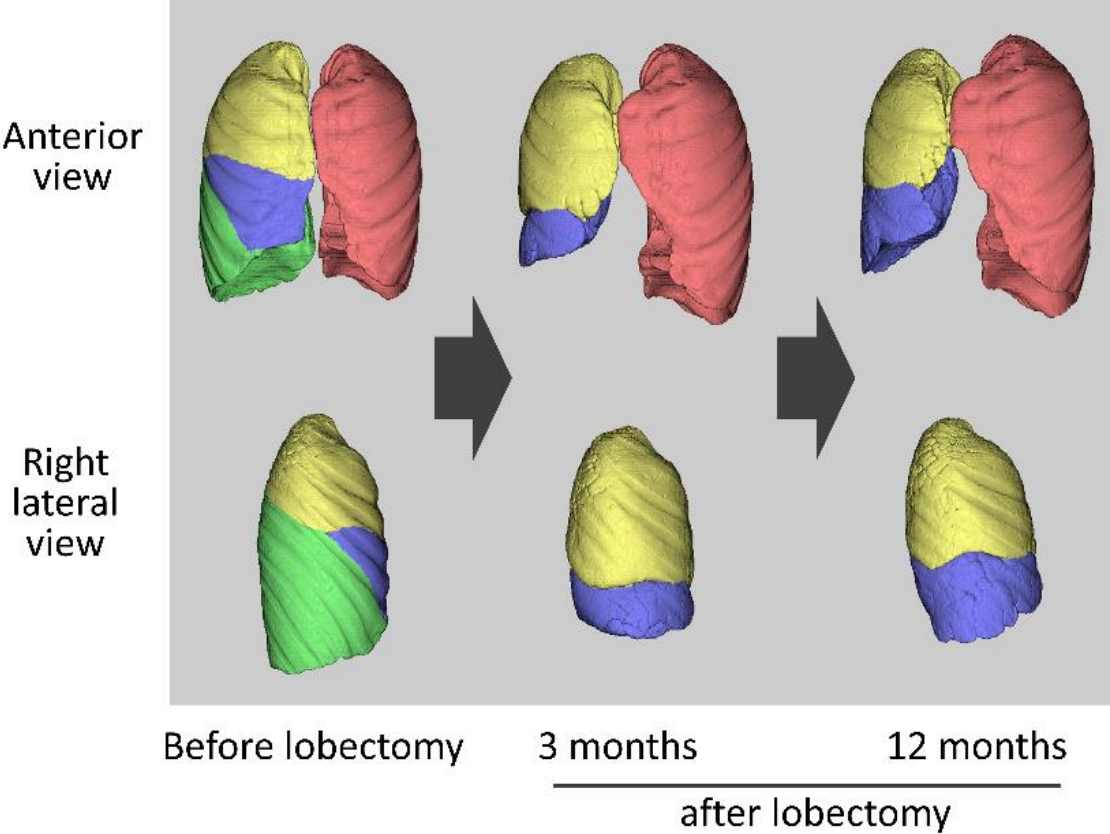
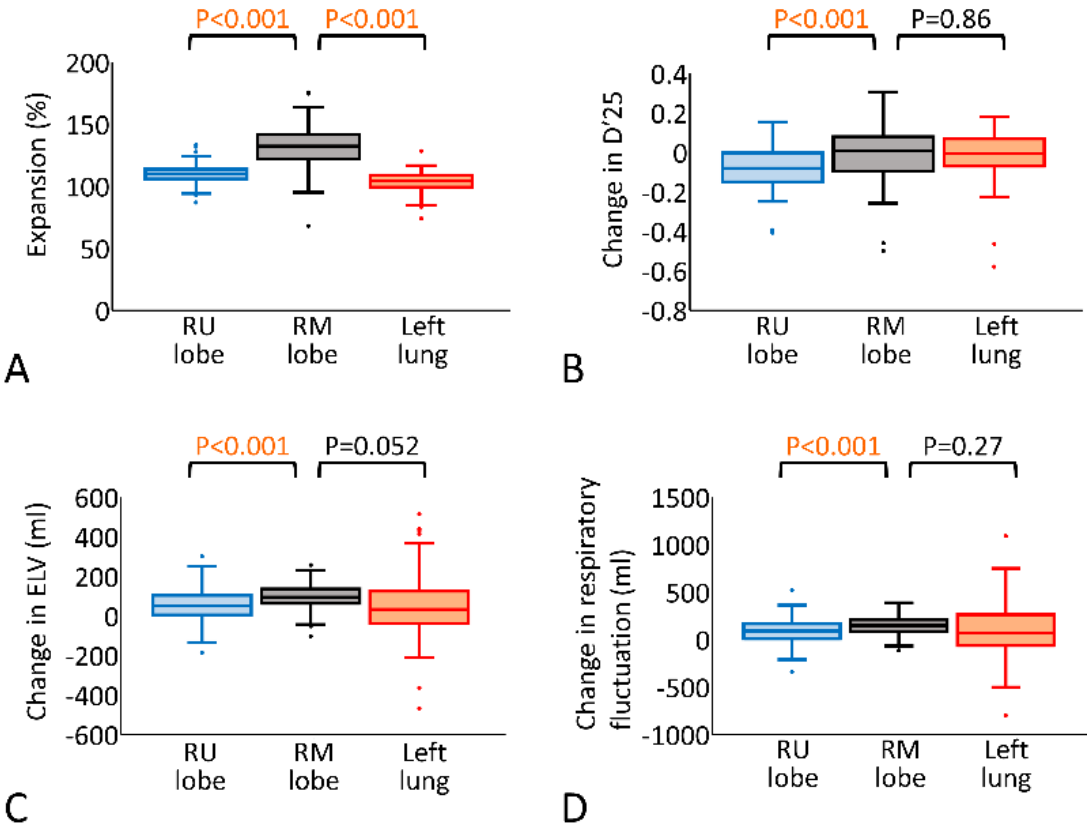
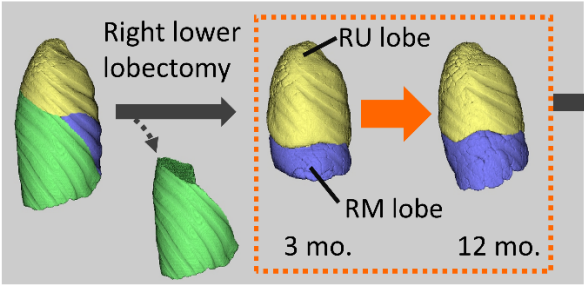


Figure 2



Graphical abstract

Donors of right lower lobe for living-donor lobar lung transplantation (N = 53)



Changes in CT in the remaining lung

CT volumetry

- Expansion
- Functional compensation

RU lobe < **RM** lobe

Fractal analysis

- Decline in structural complexity

RU lobe > **RM** lobe

The **RM lobe** had great morphological and functional reserves.