Systemic and regional pulmonary function after segmentectomy

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ABSTRACT

Objective: Segmentectomy includes numerous kinds of procedures that may result in decreased postoperative pulmonary function. This causes controversy regarding the functional advantage of segmentectomy over lobectomy. To clarify the difference between the procedures, systemic and regional pulmonary functions of the resected segments must be examined.

Methods: Pulmonary function tests and lung perfusion single-photon emission computed tomography (SPECT) were prospectively conducted before and after segmentectomy in 117 patients who were divided into groups based on resection of <2 segments ($n = 83$), ≥ 2 segments ($n = 20$), and left upper division (LUD) ($n = 14$). Left upper lobectomy ($n = 13$) was used as a control for the LUD group. Forced expiratory volume in 1 second (FEV_1) of segment and lobe were measured from a fusion image of SPECT and computed tomography.

Results: Percentage of postoperative/preoperative pulmonary function was the highest in the <2 segments group ($97\% \pm 10\%$), which was followed by the ≥ 2 segments group ($90\% \pm 9\%$), LUD group ($84\% \pm 7\%$), and left upper lobectomy group ($83\% \pm 7\%$), and the differences between the segmentectomy groups were significant ($P < .001-.03$), although there was no difference between the LUD and lobectomy groups. Whereas actual FEV_1 of preserved lobes were significantly lower than the predicted value in all segmentectomy groups ($P < .001$), the percentage of actual/predicted value in the LUD group ($43\% \pm 19\%$) was significantly lower than those in the <2 ($72\% \pm 23\%$) and ≥ 2 segments ($68\% \pm 30\%$) groups ($P < .001$ and $P = .02$, respectively).

Conclusions: Segmentectomy decreased the pulmonary function with increasing number of resected segments. LUD segmentectomy decreased both systemic and lobar function significantly due to not only large resection, but also marked depression of the preserved lobe, resulting in similar decrease as lobectomy. (J Thorac Cardiovasc Surg 2016;152:747-53)

Controversy remains regarding the superiority of pulmonary segmentectomy over lobectomy in preserving pulmonary function,¹⁻⁸ and the differences between reports may result from differences in resected segment volume. Because there are numerous types of segmentectomy with differing numbers of resected segments, postoperative pulmonary function would differ

according to the type. In particular, the left upper division (LUD) has a larger volume than the other segments, so resection seems more like an LUD lobectomy than a segmentectomy. In addition, the preserved lingular segment after LUD segmentectomy might not be able to function well because of its original small volume and destruction by surgical procedure. If the LUD segmentectomy would not differ in preserving pulmonary function from left upper lobectomy, it may partially cause

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Lung perfusion single-photon emission computed tomography/computed tomography image of lingular segment after left upper division segmentectomy.

Central Message

Segmentectomy decreased pulmonary function with increasing number of resected segments. LUD segmentectomy decreased the function equally as lobectomy.

Perspective

Differences of systemic and regional pulmonary function among segmentectomy were examined. Postoperative preserved function was the highest in the group undergoing resection of <2 segments, followed by the ≥ 2 segments group, and left upper division group. Left upper division segmentectomy decreased the function significantly due to large resection and marked depression of the preserved lobe, resulting in similar decrease as lobectomy.

See Editorial Commentary page 754.

Scanning this QR code will take you to a procedural video.

Abbreviations and Acronyms

CT	= computed tomography
FEV ₁	= forced expiratory volume in 1 second
LUD	= left upper division
PFT	= pulmonary function test
RA	= radioactivity
SPECT	= single-photon emission computed tomography

the claim that segmentectomy cannot contribute to preserving pulmonary function compared with lobectomy.

In addition, we also have to know the difference in postoperative pulmonary function in the resected segments. Although a resection of single segment is a popular procedure, the resection of >1 segment is often needed for tumors located beyond the border of a segment,⁹ which might result in a significant decrease of pulmonary function compared with the resection of a single segment. However, there have been no reports showing the difference in pulmonary function in resected segments. If the resection of multiple segments causes a significant decrease in postoperative pulmonary function compared with resection of a single segment, it should be taken into account while making decisions regarding segmentectomy and also for comparison studies of pulmonary function between segmentectomy and lobectomy.

To compare the preserved function among the segmentectomy procedures, we examined not only the systemic function measured by a routine pulmonary function test (PFT), but also the regional functions of lobes and segments measured by lung perfusion with single-photon emission computed tomography (SPECT).

MATERIALS AND METHODS

Patients

Between January 2013 and June 2015, a total of 143 patients underwent segmentectomy for lung cancer using previously reported techniques^{10,11} (see Video 1). Of these, 26 patients were excluded because they had not undergone both pre- and postoperative perfusion SPECT/computed tomography (CT) (n = 8) or they underwent additional resections for other lung lesions (n = 18). The remaining 117 patients underwent PFT and perfusion SPECT/CT before and >6 months (median, 7 months; range, 6-13 months) after segmentectomy (Table 1). Among these patients, resection of <2 segments was conducted in 83 patients, resection of ≥2 segments other than the LUD was conducted in 20 patients, and LUD segmentectomy was conducted in 14 patients. Basal segmentectomy was conducted in 1 patient in the ≥2 segments group. The mean number of resected subsegments in the <2 segments, ≥2 segments, and LUD groups were 2.3 ± 0.8, 4.6 ± 0.8, and 6 ± 0, respectively. As a control for the LUD group, 13 patients treated by left upper lobectomy were used (Table 1). No significant differences in age, sex, smoking history, or pulmonary function were evident among the groups, but mean tumor size in the LUD group (3.1 ± 1.5 cm) was significantly larger than that in the <2 segments (1.7 ± 0.6 cm; *P* < .001) and ≥2 segments groups (2.0 ± 0.7 cm; *P* = .008).

VIDEO 1. Segmentectomy of right S2 and S1a. Detailed techniques are explained in subtitles on each scene. Video available at: [http://www.jtcvsonline.org/article/S0022-5223\(16\)30497-4/addons](http://www.jtcvsonline.org/article/S0022-5223(16)30497-4/addons).

PFT

Vital capacity, forced vital capacity, and forced expiratory volume in 1 second (FEV₁) were measured using a dry rolling-seal spirometer (CHESTAC-9800DN; Chest, Tokyo, Japan). The percentage of postoperative function to preoperative function was measured from the PFT using the following formula:

$$[\text{Postoperative FEV}_1 / \text{Preoperative FEV}_1] \times 100\%$$

TABLE 1. Patient characteristics

	Number of resected segments			
	<2	≥2	LUD	LUL
Mean age, y	67 ± 10	72 ± 6	69 ± 6	68 ± 8
Sex				
Male	49 (59)	12 (60)	9 (64)	7 (54)
Female	34 (41)	8 (40)	5 (36)	6 (46)
Smoking				
Nonsmoker	40 (48)	7 (35)	7 (50)	6 (46)
Exsmoker	19 (23)	6 (30)	3 (21)	5 (38)
Smoker	24 (29)	7 (35)	4 (29)	2 (16)
Preoperative pulmonary function				
FEV ₁ , L	2.2 ± 0.7	2.2 ± 0.6	2.4 ± 0.6	2.4 ± 0.7
FEV ₁ /FVC, %	70 ± 11	69 ± 13	69 ± 11	72 ± 8
%FEV ₁ , %	105 ± 23	114 ± 23	117 ± 27	114 ± 19
Postoperative pulmonary function				
Predictive FEV ₁ , L	2.1 ± 0.6	2.0 ± 0.5	2.0 ± 0.5	1.9 ± 0.6
Actual FEV ₁ , L	2.1 ± 0.6	2.0 ± 0.5	2.0 ± 0.5	2.0 ± 0.5
Mean tumor size, cm	1.7 ± 0.6	2.0 ± 0.7	3.1 ± 1.5	3.4 ± 1.5
Lobe underwent segmentectomy				
Right upper lobe	34 (41)	1 (5)	0	0
Right lower lobe	17 (20)	7 (35)	0	0
Left upper lobe	17 (20)	8 (40)	14 (100)	13 (100)
Left lower lobe	15 (19)	4 (20)	0	0
Number of subsegments	2.3 ± 0.8	4.6 ± 0.8	6 ± 0	10 ± 0
Total number of cases	83	20	14	13

Values are presented as n (%) or mean ± standard deviation. LUD, Left upper division; LUL, left upper lobe; FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity.

FIGURE 1. Perfusion images of the left upper division of the left upper lobe on single-photon emission computed tomography. A, Sagittal. B, Coronal. C, Axial. D, 3-Dimensional imaging. The arrow shows a tumor.

Perfusion SPECT/CT

A 185 MBq of ^{99m}Tc -macroaggregated human serum albumin (Daiichi Radioisotope Laboratories Ltd, Tokyo, Japan) was administered intravenously for each patient. Perfusion scintigraphy images and CT images were obtained using a SPECT scanner with a variable-angle digital gamma camera (E-CAM; Toshiba, Tokyo, Japan) and a 64-multidetector-row CT scanner (Aquilion; Toshiba), respectively. Each image was fused to make a SPECT/CT image using AZE Virtual Place Raijin software (AZE, Tokyo, Japan).

Measurement of FEV_1 of Segments

Images of each segment were traced on the preoperative SPECT/CT image using a region of interest for which radioactivity (RA) was measured (Figure 1). FEV_1 of the segment was measured according to the following formula:

$$\text{FEV}_1 \text{ on PFT} \times [\text{RA of the segment} / \text{RA of the whole lung}]$$

Measurement of FEV_1 of Lobes

Images of lobes before and after segmentectomy were traced on the SPECT/CT image for which RA was measured (Figure 2). FEV_1 of the lobe before or after segmentectomy was measured according to the following formula:

$$\text{Pre — or postoperative } \text{FEV}_1 \text{ on PFT} \times [\text{RA of the lobe} / \text{RA of the whole lung}]$$

Percentage of Actual Function to Predicted Value in Preserved Lobes

Predicted function of preserved lobes after segmentectomy were calculated from the preoperative SPECT/CT according to the following formula:

$$\text{FEV}_1 \text{ of the lobe} - \text{FEV}_1 \text{ of the segment}$$

Actual function of preserved lobes after segmentectomy were calculated from the postoperative SPECT/CT according to the following formula:

$$\text{FEV}_1 \text{ on PFT} \times [\text{RA of the preserved lobe} / \text{RA of the whole lung}]$$

The percentage of the actual function to the predicted value in preserved lobes was measured from the 2 values shown above, according to the following formula:

$$[\text{Actual } \text{FEV}_1 \text{ of the preserved lobe} / \text{Predicted } \text{FEV}_1 \text{ of the preserved lobe}] \times 100\%$$

FIGURE 2. Perfusion images of the left upper lobe before (*left*) and after (*right*) left upper division segmentectomy in the same patient shown in Figure 1. A, Sagittal. B, Coronal. C, Axial. D, 3-Dimensional imaging. The *arrows* show a tumor.

Eligibility

This prospective study for examining perfusion scintigraphy with SPECT/CT before and after major lung resection was approved by the Ethics Committee of Kameda Medical Center in 2012 (approval No. 12-085). Written informed consent forms were obtained from all patients after detailed information was provided by their surgeons.

Statistical Analysis

After confirming the variance among the 3 groups by analysis of variance, differences between the 2 groups were analyzed using a 2-tailed Student *t* test or a Mann-Whitney *U* test. The difference between the predicted and actual functions of the preserved lobes in each group was examined using a paired *t* test. All values in the text and Table 1 are given as mean $\pm$ standard deviation.

RESULTS

No major postoperative complications were encountered after segmentectomy in any of the patients. Figure 3 shows the percentages of postoperative/preoperative systemic pulmonary function (FEV_1 in PFT) in the 3 segmentectomy groups and left upper lobectomy; that is, $97\% \pm 10\%$ in the <2 segments group, $90\% \pm 9\%$ in the ≥ 2 segments group, $84\% \pm 7\%$ in the LUD group, and $83\% \pm 7\%$ in the left upper lobectomy group. The differences were significant between the <2 segments group and ≥ 2 segments group ($P = .01$), between the <2 segments group and the LUD group ($P < .001$), and between the ≥ 2 segments group and the LUD group ($P = .03$). There was no significant difference between the LUD and left upper lobectomy

groups ($P = .68$). These data indicate that pulmonary function after segmentectomy decreased with increasing number of resected segments and LUD segmentectomy did not differ from lobectomy in preserving pulmonary function.

Figure 4 shows the FEV_1 of the resected segments, which was measured by preoperative SPECT/CT; that is, 0.13 ± 0.08 L in the <2 segments group, 0.19 ± 0.14 L

FIGURE 3. Percentage of postoperative forced expiratory volume in 1 second (FEV_1) compared with the preoperative FEV_1 from pulmonary function test. NS, Not significant; LUD, left upper division.

FIGURE 4. Forced expiratory volume in 1 second (FEV_1) of the resected segment. LUD, Left upper division.

in the ≥ 2 segments group, and 0.37 ± 0.12 L in the LUD group. The values in the LUD group were significantly higher than those in the <2 segments and ≥ 2 segments groups ($P < .001$ each). Whereas the values in the <2 segments group were lower than those in the ≥ 2 segments group, the difference did not reach significance ($P = .09$). These data indicate that the LUD segmentectomy resected a lot more functioning lung than did the procedures employed for the other 2 groups.

Figure 5 shows the difference between the predicted FEV_1 and actual FEV_1 of the preserved lobe in each group. The predicted and actual values of the preserved lobe in the <2 segments group were 0.38 ± 0.15 L and 0.27 ± 0.13 L, respectively; those in the ≥ 2 segments group were 0.37 ± 0.2 L and 0.22 ± 0.1 L, respectively; and those in

FIGURE 5. Predicted forced expiratory volume in 1 second (FEV_1) and postoperative actual FEV_1 of the preserved lobe. LUD, Left upper division.

the LUD group were 0.22 ± 0.09 L and 0.09 ± 0.04 L, respectively. All groups showed significantly lower actual values than predicted ($P < .001$). Although the actual values of the preserved lobes in the LUD group were significantly lower than those in the <2 segments and ≥ 2 segments groups ($P < .001$), no significant difference was seen between the latter 2 groups ($P = .19$). These data indicate that the preserved lobe after segmentectomy could not function as predicted in all segmentectomies and the preserved lobe function was the lowest in the LUD segmentectomy group among the 3 groups.

Figure 6 shows the percentage of actual/predicted FEV_1 of the preserved lobe; that is, $72\% \pm 23\%$ in the <2 segments group, $68\% \pm 30\%$ in the ≥ 2 segments group, and $43\% \pm 19\%$ in the LUD group. The LUD group showed a significantly lower percentage than the <2 and ≥ 2 segments groups ($P < .001$ and $P = .02$, respectively). There was no significant difference between the <2 and ≥ 2 segments groups ($P = .63$). These data indicate that LUD segmentectomy resulted in a more marked decrease in preserved lobe function than predicted. This decrease was more significant than in the other 2 groups.

DISCUSSION

To measure the regional pulmonary function, the following methods were employed: calculation of the number of subsegments^{12,13}; CT volumetry of the functioning lung^{14,15}; and a lung perfusion SPECT/CT, which shows the anatomy of the lung on SPECT images.¹⁶⁻¹⁸ Of these, perfusion SPECT/CT has been reported to be the most accurate method for predicting postoperative pulmonary function.¹ That is the reason why we used it for the present study.

The present study clarified the following 3 points: pulmonary function after segmentectomy decreases with increasing number of resected segments; LUD segmentectomy decreases both the systemic and lobe function significantly more than the other types of segmentectomy, resulting in similar decrease as lobectomy; and although all 3 groups showed a significant decrease in actual lobe function compared with predicted, the decrease was most significant in the LUD segmentectomy group.

It makes sense that systemic pulmonary function after segmentectomy decreases with increasing number of resected segments. The mean numbers of resected subsegments in the <2 segments, ≥ 2 segments, and LUD groups in the present study were 2.3 ± 0.8 , 4.6 ± 0.8 , and 6 ± 0 , respectively, as shown in Table 1, which caused the decrease in postoperative function in the respective groups. However, the mean postoperative change after resection of patients in the <2 segments group reached to $97\% \pm 10\%$, which might be higher than expected because a human lung has 42 subsegments in total; specifically, 22 on the right side and 20 on the left. Therefore, the mean

FIGURE 6. Percentage of the actual forced expiratory volume in 1 second (FEV_1) to the predicted FEV_1 in the preserved lobe. NS, Not significant; LUD, left upper division.

number of 2.3 subsegments in the <2 segments group corresponds to 6% of the entire lung (2.3 out of 42 subsegments), the result being that 94% of lung function is predicted to be preserved, which increased to 97% in the present study. We believe that it is caused by compensatory lung growth after lung resection.^{12,19} In addition, the better recovery of pulmonary function in the <2 segments group compared with those in the other 2 groups is due to lesser destruction of the lobe. These data indicate that the resection of ≥ 2 segments may have little advantage for preserving pulmonary function, and that the inferiority of segmentectomy for ≥ 2 segments compared with <2 segments for preserving pulmonary function should be taken into account in comparison studies between segmentectomy and lobectomy.

The present study showed the inferiority of LUD segmentectomy to other types of segmentectomy for preserving pulmonary function. The FEV_1 of the preserved lingular segment after LUD segmentectomy was just 0.09 ± 0.04 L. From our data, we believe it is caused by the following 2 situations: the LUD segment has 6 subsegments, which is much larger than the other segments; and LUD segmentectomy caused an unexpected, significant decrease of the lingular segment, which might be similar to right middle lobe syndrome after right upper lobectomy. Right upper lobectomy has been reported to result in functional decrease of the right middle lobe caused by excessive upward bending and rotation of the middle lobar bronchus.^{20,21} Yoshimoto and colleagues²² reported that the function of the right middle lobe is significantly decreased after right upper lobectomy compared with after segmentectomy of the right upper lobe, reportedly caused by less displacement of the right middle lobe after segmentectomy than after lobectomy. Because the LUD and left lingular

segment correspond to the right upper lobe and right middle lobe, respectively, LUD segmentectomy would make the lingular segment fall into a condition resembling right middle lobe syndrome after right upper lobectomy. Therefore, when a tumor is small enough to be treated with a resection of either the left apicodorsal segment (S1+2) or ventral segment (S3), single segmentectomy is preferable to LUD segmentectomy for preserving pulmonary function. Although the present study could not examine the results of basal segmentectomy, basal segmentectomy would end up with the same result as LUD segmentectomy because of its large volume.

CONCLUSIONS

Pulmonary function after segmentectomy decreased with increasing number of resected segments, which should be taken into account not only for decision making regarding segmentectomy, but also in comparison studies of pulmonary function between segmentectomy and lobectomy. LUD segmentectomy decreased both systemic and lobar function compared with other types of segmentectomy, caused by not only by the large segment in LUD, but also by the marked depression of the lingular segment resulting in functional decrease similar to that seen in left upper lobectomy. LUD segmentectomy should be conducted only in patients with marginal pulmonary function and also should be excluded from comparison studies of pulmonary function between segmentectomy and lobectomy.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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