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Thoracoscopic left S^{1+2} segmentectomy as a good resolution for preserving pulmonary function

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Key question

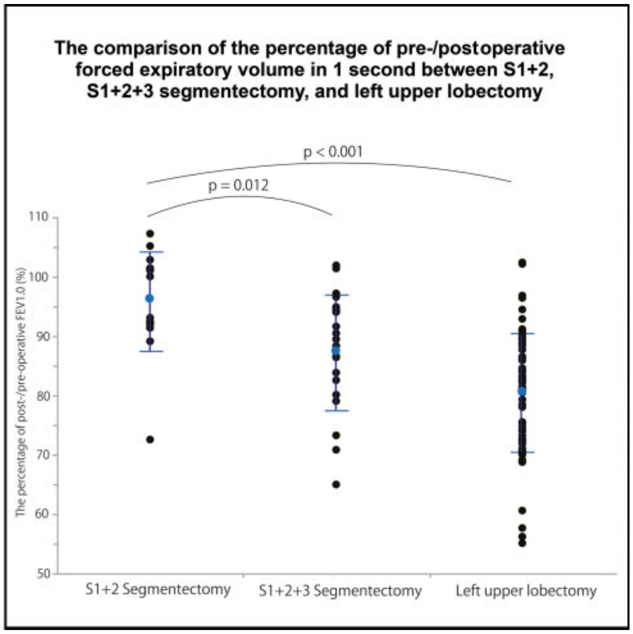
How much lung function is preserved after S^{1+2} segmentectomy compared to that after other segmentectomies in the left upper lobe?

Key finding(s)

Postoperative lung function and the residual lobe were best preserved after S^{1+2} segmentectomy.

Take-home message

Thoracoscopic S^{1+2} segmentectomy for lung cancer could be a good alternative to preserve postoperative lung function in the left upper apical lobe.



Abstract

OBJECTIVES: Segmentectomies such as S^{1+2}, S^{1+2+3} and S^{4+5} segmentectomy are used to treat patients with non-small-cell lung cancer (NSCLC) in the left upper lobe. However, the preservable lung volume and changes after such segmentectomies remain unknown. We compared the residual pulmonary function after thoracoscopic segmentectomy or lobectomy in the left upper lobe and examined the efficacy of S^{1+2} segmentectomy regarding postoperative pulmonary function.

METHODS: Patients with left upper lobe NSCLC who underwent thoracoscopic segmentectomy or lobectomy were included. Spirometry and computed tomography were performed before and 6 months after resection, and the ipsilateral preserved lobe volume was calculated using 3-dimensional computer tomography. The percentage of postoperative/preoperative forced expiratory volume in 1 s and actual/predicted regional forced expiratory volume in 1 s (preservation rate) in the residual lobe were compared.

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RESULTS: Eighty-eight patients underwent lobectomy and 70 patients underwent segmentectomy (23 S^{1+2}, 35 S^{1+2+3} and 12 S^{4+5} segmentectomies). The percentage of postoperative/preoperative forced expiratory volume in 1 s was 97 in S^{1+2}, 82 in S^{1+2+3}, 86 in S^{4+5} segmentectomy and 73 in left upper lobectomy, indicating that segmentectomy could be a meaningful approach to preserve pulmonary function. The preservation rate was 83% in S^{1+2} and 62% in S^{1+2+3} segmentectomy and was significantly higher in S^{1+2} than in S^{1+2+3} segmentectomy ($P < 0.001$).

CONCLUSIONS: Postoperative pulmonary function and the preservable lung volume of the residual lobe after thoracoscopic S^{1+2} segmentectomy were well-preserved among other segmentectomies and lobectomy. Thoracoscopic S^{1+2} segmentectomy is a good alternative for preserving postoperative function.

Keywords: Left upper lobe • Pulmonary function • Segmentectomy • Thoracoscopic surgery

ABBREVIATIONS

3D-CT	3-Dimensional computed tomography
FEV1.0	Forced expiratory volume in 1 s
NSCLC	Non-small-cell lung cancer
MDCT	Multi-detector row CT

INTRODUCTION

The use of segmentectomy has increased and gained interest by many surgical groups for resecting small-sized early non-small-cell lung cancer (NSCLC) since this technique may better preserve lung function compared to lobectomy [1–4]. We previously reported that segmentectomy better preserved pulmonary function compared with lobectomy, using a novel 3-dimensional computed tomography (3D-CT) volumetric method [5]. In the previous study, although the decrease in actual lung function of the residual lobe was greater than predicted, we found that the residual lobe volume rescued by segmentectomy was different according to the resected segments. Therefore, the investigation should be broadened to more precisely assess postoperative lung function in each type of segmentectomy.

The left upper lobe is one of the biggest lobes in the lungs, and segmentectomy has been well established by thoracic surgeons. For lung cancer located in the left apical segment, there are options for surgical procedures including S^{1+2} segmentectomy, S^{1+2+3} segmentectomy and left upper lobectomy. Postoperative functional benefit could be expected if the resected areas are limited to 1 segment, because pulmonary function after segmentectomy was shown to decrease with increasing number of resected segments [5, 6]. In this context, given that the oncological margin would be secured, S^{1+2} segmentectomy could be indicated rather than left upper lobectomy or S^{1+2+3} segmentectomy, in terms of preserving postoperative lung function. However, there have been no reports focusing on the comparison of functional changes after S^{1+2} segmentectomy in the left upper lobe.

Herein, we examined the feasibility of thoracoscopic left S^{1+2} segmentectomy and compared its functional benefit to other segmentectomies, including S^{1+2+3}, S^{4+5} segmentectomy and left upper lobectomy using a novel 3D-CT volumetric method.

MATERIALS AND METHODS

Patients

We examined consecutive patients who underwent thoracoscopic left upper segmentectomy or lobectomy at Hyogo Cancer Center between January 2012 and December 2018. Study parameters included sex, age, smoking history, pulmonary function and perioperative outcomes (Table 1). The basic selection criteria for thoracoscopic segmentectomy included the following: (i) patients with peripheral small-sized NSCLC with ground glass opacity, indicating clinical T1a/bN0M0 cancer (based on the 8th edition lung cancer stage classification); (ii) patients with compromised resection who were considered poor candidates for lobectomy because of their limited cardiopulmonary reserve; and (iii) patients with pulmonary metastases or benign lesions. The Hyogo Cancer Center Institutional Review Board approved the study, and each participant provided their informed consent.

All patients who received thoracoscopic segmentectomy and lobectomy underwent a 3D-CT scan and lung function test before and 6 months after the operation. Patients treated with induction chemoradiotherapy or who had a history of lung surgery were excluded from this study.

Surgical procedures

All lobectomy and segmentectomy procedures were performed by the thoracoscopic approach, as described elsewhere [7]. A representative image and procedure for thoracoscopic left S^{1+2} segmentectomy are shown in Fig. 1 and Video 1. Briefly, the surgery was generally performed through 4 port sites (2–4 cm) without rib spreading. First, the segmental vein was exposed and resected, while the intersegmental vein was preserved and detached towards the periphery. After the ligation of the segmental artery, we then identified the accurate bifurcation of B^{1+2}/B^3 and detached the bronchus to allow for dissection with a stapler after lung inflation on the operating side. The inflation–deflation line gradually became clear when the lung was re-collapsed. Besides cutting the intersegmental plane along the intersegmental veins and inflation-deflation line, the systemic injection of indocyanine green (0.3 mg/kg) helped to identify the demarcation line in some cases [8]. The pulmonary parenchyma was dissected from the hilum towards the periphery with a stapling device. This ensured that the surgical margin from the tumour was sufficiently secured, while the intersegmental veins were preserved. Electrocautery was used to dissect along the demarcation line until mechanical stapling became feasible. In particular, we kept in mind that mechanical stapling line should be in a line to minimize the number of junctional points, which helps to avoid postoperative fistula of the bronchioles. In addition, we performed pneumostasis with thin type (0.15 mm) polyglycolic acid mesh (Neoveil; Gunze, Osaka, Japan) and fibrin glue (Beriplast; CSL Behring, Tokyo, Japan) after lung resection to stop air leak thoroughly.

Table 1: Summary of clinical variables

Clinical viable	Segmentectomy			LUL (n = 88)
	S^{1+2} (n = 23)	S^{1+2+3} (n = 35)	S^{4+5} (n = 12)	
Gender (male/female)	12/11	22/13	4/8	51/37
Age (years), mean ± SD	70.8 ± 8.4	71.7 ± 6.2	70.3 ± 9.7	68.9 ± 8.9
Smoking history (yes/no)	13/10	22/13	4/8	54/34
FEV1.0 (l), mean ± SD	2.04 ± 0.53	2.20 ± 0.56	1.99 ± 0.56	2.27 ± 0.55
FEV1.0/FVC (%), mean ± SD	71.9 ± 12.0	71.7 ± 11.0	71.6 ± 5.3	75.2 ± 9.8
Tumour size (cm), mean ± SD	2.0 ± 0.5	2.3 ± 0.8	1.9 ± 0.5	2.6 ± 1.0
Histology, *n*				
Ad	15	29	11	68
Sq	3	4	1	9
Others	5	2	0	11
Stage, *n*				
AIS	3	1	1	0
IA	14	26	9	43
IB	3	6	1	27
IIA	0	0	0	2
IIB	2	1	0	8
III or IV	0	1	1	8
Operation time (min), mean ± SD	199 ± 51	181 ± 33	174 ± 30	195 ± 39
Blood loss (ml), mean ± SD	27.8 ± 24.2	36.3 ± 35.2	31.6 ± 15.8	55.2 ± 53.9
Postoperative complication (%), *n* (%)	0 (0)	2 (6)	0 (0)	11 (13)
Lung fistula, *n*	0	0	0	9
Supraventricular arrhythmia, *n*	0	1	0	2
Recurrent laryngeal nerve palsy, *n*	0	1	0	0

AIS: adenocarcinoma *in situ*; Ad: adenocarcinoma; FEV1.0: forced expiratory volume in 1 s; FVC: forced vital capacity; LUL: left upper lobectomy; Sq: squamous cell carcinoma; SD: standard deviation; S^{1+2}: S^{1+2} segmentectomy; S^{1+2+3}: S^{1+2+3} segmentectomy; S^{4+5}: S^{4+5} segmentectomy.

Computed tomography and 3-dimensional lung image construction

All chest CT examinations were performed with 16- or 80-multi-detector row CT scanners (Aquilion 16 or Prime, Toshiba Medical Systems, Otawara, Japan). The entire lung was scanned from the lung apex to the diaphragm during a single breath held at end-inspiration. The scan parameters of the multidetector row CT examination were as follows: 130 kVp, 150 mAs, collimation 1 mm × 16 mm, rotation 0.5 s, or 120 kVp, 390–500 mAs, collimation 0.5 mm × 80 mm, rotation 0.35 s, 512 × 512 matrix, field of view 320 mm and reconstruction 1/1 mm. After the initial non-contrast-enhanced multidetector row CT examination, 100 ml of iodine contrast agent (Iopamiron 300; Bayer AG, Leverkusen, Germany) was administered to each patient.

Three-dimensional imaging was reconstructed from the CT data using the SYNAPSE VINCENT software programme (Fujifilm Corporation, Tokyo, Japan). Besides the capability of reconstructing 3D images of the pulmonary vessels and bronchial trees, this software programme enabled the calculation of the bronchial ventilation area using an algorithm based on the direction and diameter of the bronchi. This function allowed for the measurement of the volume of each lobe including the resected lobe and the residual lobe rescued by segmentectomy using the preoperative CT data. These volumes after thoracoscopic segmentectomy were also calculated from the postoperative CT data.

The image interpretation and data analysis

The regional forced expiratory volume in 1 s (FEV1.0) of the residual lobe rescued by segmentectomy was measured from the volumetric and spirometric parameters using the following formula:

$$\text{FEV1.0}\times(\text{the regional subjected lung volume}/\text{the whole lung volume}).$$

The predicted FEV1.0 of the left upper segments to be preserved after segmentectomy was calculated using the following formula:

$$\text{Preoperative FEV1.0}\times(\text{the subjected lung volume}/\text{whole lung volume measured from preoperative 3D}-\text{CT}).$$

Similarly, the actual FEV1.0 of the residual preserved lobe was calculated using the following formula:

$$\text{Actual FEV1.0}\times(\text{the subjected lung volume}/\text{whole lung volume measured from postoperative 3D}-\text{CT}).$$

The percentage of actual/predicted FEV1.0 of the residual lobe was defined as the preservation rate.

Statistical analysis

All statistical analyses were performed using the JMP software programme (Version 13, SAS Inc., Cary, NC, USA). All values were expressed as the mean ± standard deviation.

The difference between the predicted and actual functions of the preserved lobe in each group was examined using a paired *t*-test. In comparison with complications and clinical factors, categorical and continuous variables were analysed by the χ^2 test and unpaired *t*-test, respectively. A *P*-value of <0.05 was considered statistically significant.

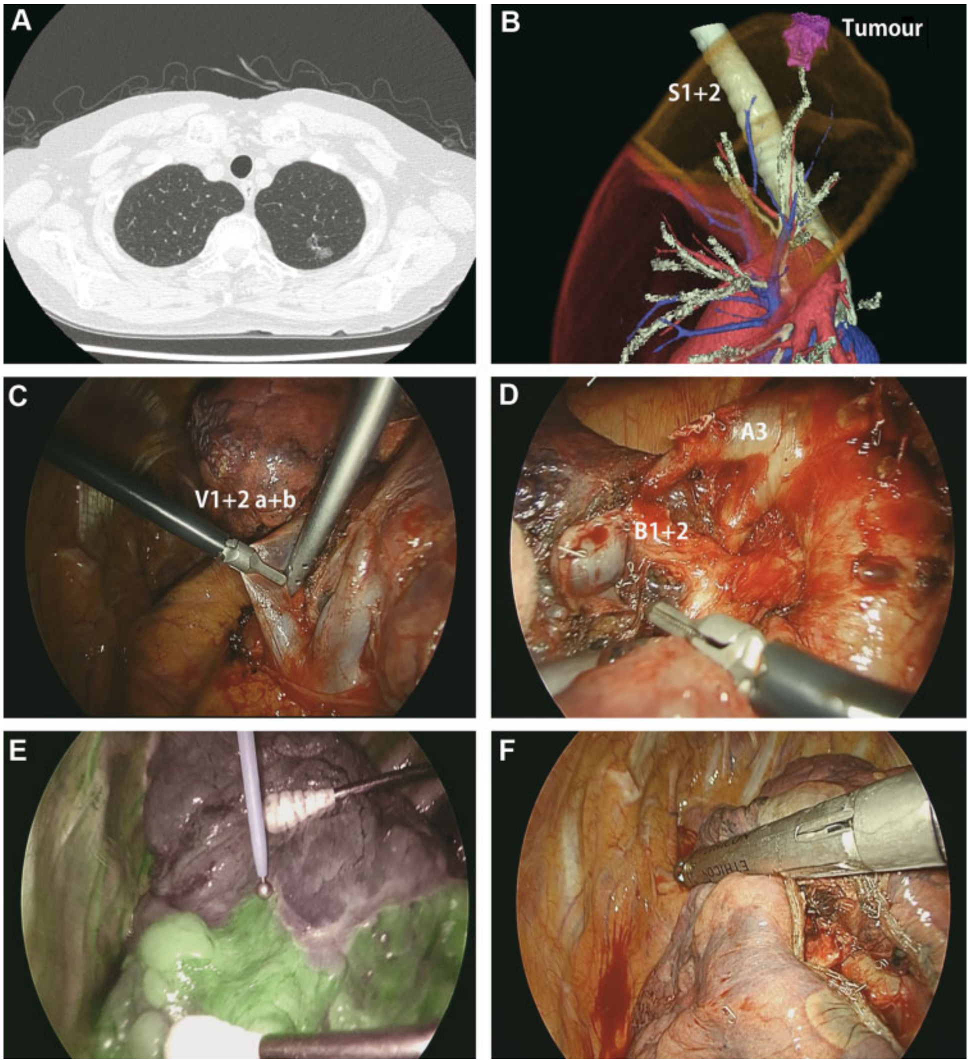


Figure 1: A representative case of thoracoscopic left S^{1+2} segmentectomy. (**A**) Computed tomography findings showing part-solid nodule (yellow arrow) in left S^{1+2}. (**B**) Three-dimensional vasculature image and visual guidance of virtual S^{1+2} segmentectomy produced by Synapse Vincent. (**C**) The operative procedure of thoracoscopic S^{1+2} segmentectomy. (a) The segmental veins including intersegmental veins were exposed and detached towards the periphery. (b) After the ligation of the segmental artery and vein, B^{1+2} was identified and dissected. (c, d) In reference to the inflation–deflation line or systemic indocyanine green injection, intersegmental plane was dissected using staplers.

RESULTS

Surgical results

The patient characteristics, and the results of the overall operation and resected segment are summarized in Table 1. The average operation time and the amount of bleeding were 184 ± 39 min and 45 ± 32 ml in segmentectomy and 195 ± 40 min and 55.2 ± 46.9 ml in lobectomy, respectively. Among segmentectomy cases, the surgical times of S^{1+2} segmentectomies tended to be longer than those of other segmentectomies (199 ± 51 vs 181 ± 32 min, respectively).

Regarding postoperative complications, 1 patient presented with sick sinus syndrome on postoperative day 3, 1 patient presented with hoarseness due to recurrent nerve paralysis in segmentectomy, 9 patients presented with prolonged air leak and 2 patients presented with arterial fibrillation in the left upper lobectomy. Notably, no patients presented with postoperative prolonged air leak in segmentectomy. The complication rate was significantly lower among segmentectomies compared to lobectomies (3% vs 13%, respectively, $P = 0.021$). No postoperative deaths or additional resections due to R1/2 resection occurred in these populations.

Postoperative lung function after segmentectomy compared with lobectomy

Figure 2 compares the percentage of the postoperative/preoperative FEV1.0 between segmentectomy and lobectomy groups. The percentage of postoperative/preoperative FEV1.0 was 97 in S1 + 2, 82 in S1 + 2 + 3, 86% in S^{4+5} segmentectomy and 73 in left upper lobectomy. The percentage of postoperative/preoperative FEV1.0 was significantly higher in all segmentectomy groups (including S^{1+2}, S^{1+2+3} and S^{4+5} segmentectomy) compared with left upper lobectomy ($P < 0.001$). These findings indicate that segmentectomy preserved the whole lung function better than lobectomy in the left upper lobe.

In addition, when comparing the segmentectomy groups only, the percentage of postoperative/preoperative FEV1.0 in S^{1+2} segmentectomy and S^{4+5} was significantly higher than that of S^{1+2+3} segmentectomy ($P = 0.014$ and $P = 0.035$, respectively). These findings indicate that the residual lung function could be decreased according to the increasing extent of the resected segments.

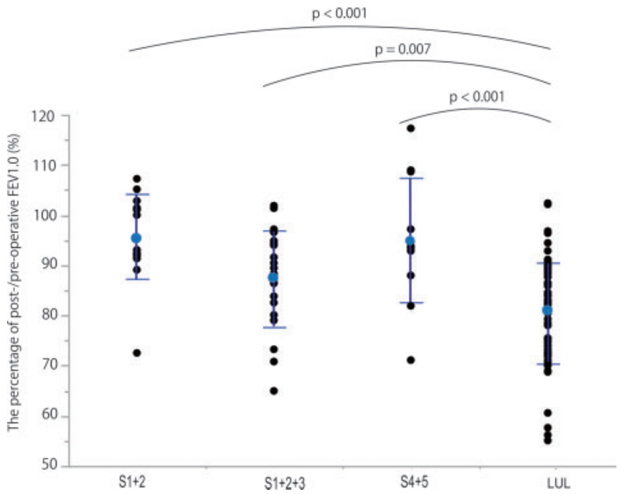


Figure 2: The comparison of the percentage of preoperative/postoperative FEV1.0 between S^{1+2}, S^{1+2+3} and S^{4+5} segmentectomy, and left upper lobectomy. The percentage of preoperative/postoperative FEV1.0 was significantly higher in all segmentectomy types than in the LUL. FEV1.0: forced expiratory volume in 1 s: LUL: left upper lobectomy; S^{1+2}: S^{1+2} segmentectomy; S^{1+2+3}: S^{1+2+3} segmentectomy; S^{4+5}: S^{4+5} segmentectomy.

Residual lung function after S^{1+2} and S^{1+2+3} segmentectomies

Figure 3 shows the predicted and the actual residual lobe volume in S^{1+2} and S^{1+2+3} segmentectomies. The actual residual lobe volume was significantly lower than the predicted volume in each procedures (S^{1+2}; $P = 0.037$ and S^{1+2+3}; $P < 0.001$). The decrease in the residual lobe volume after S^{1+2+3} segmentectomy was more remarkable as compared with S^{1+2} segmentectomy.

Figure 4 shows the comparison of the preservation rate between S^{1+2} and S^{1+2+3} segmentectomies. Each preservation rate was: S^{1+2}, 83%; and S^{1+2+3}, 62%. The preservation rate of S^{1+2} segmentectomy was significantly higher than that of S^{1+2+3} segmentectomy ($P < 0.001$), indicating that the preservable lung volume of the residual lobe after S^{1+2} segmentectomy was well-maintained compared to that after S^{1+2+3} segmentectomy. In contrast, the actual residual lobe function after S^{1+2+3} segmentectomy was significantly decreased than expected preoperatively.

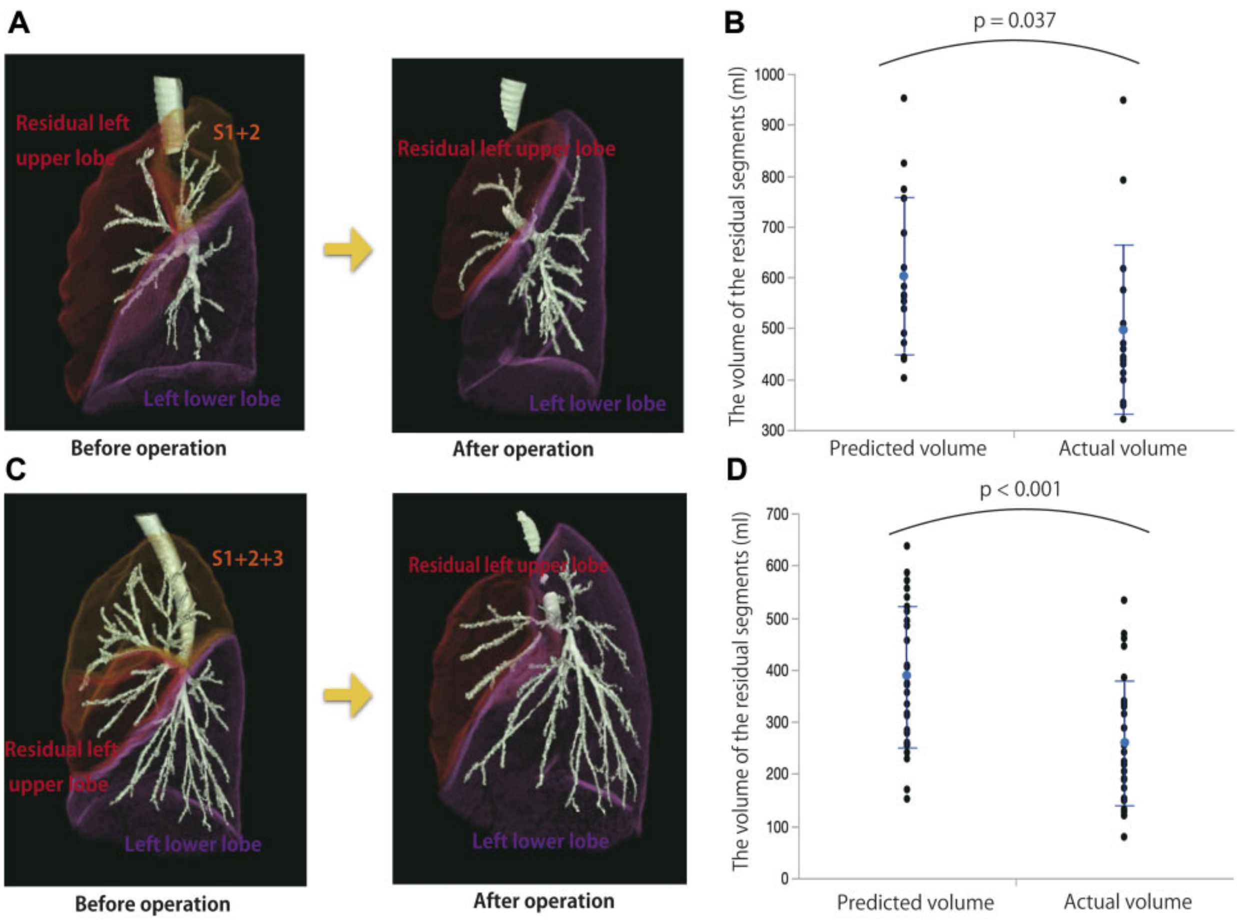


Figure 3: The change in the left upper residual lobe volume before and after S^{1+2} and S^{1+2+3} segmentectomy (**A**, **C**). The actual residual lobe volume was significantly lower than the predicted volume in each procedures (S^{1+2}; $P = 0.037$ and S^{1+2+3}; $P < 0.001$) (**B**, **D**) and its change was more remarkable after S^{1+2+3} segmentectomy. FEV1.0: forced expiratory volume in 1 s; S^{1+2}: S^{1+2} segmentectomy; S^{1+2+3}: S^{1+2+3} segmentectomy.

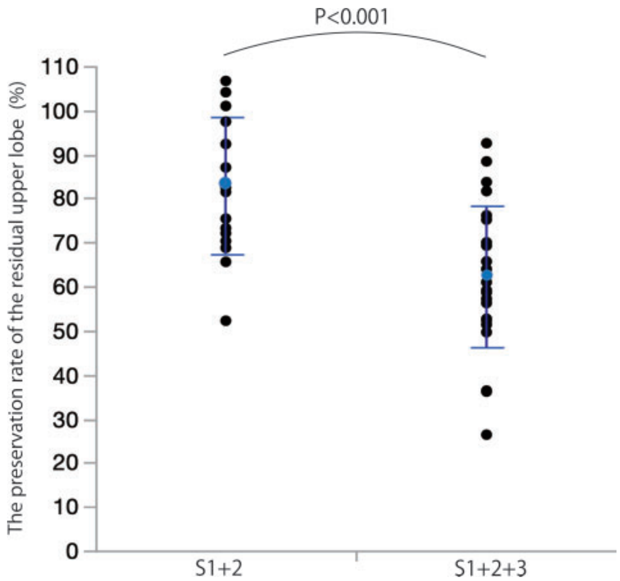
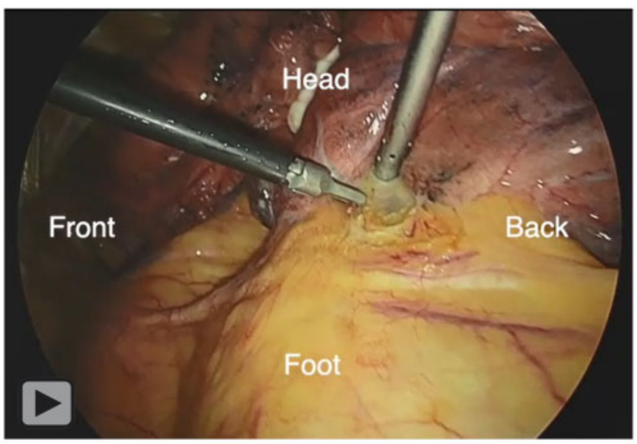


Figure 4: The comparison of the preservation rate between S^{1+2} and S^{1+2+3} segmentectomy. The preservation rate of the residual left upper lobe after S^{1+2} segmentectomy was significantly higher than that after S^{1+2+3} segmentectomy ($P < 0.001$). S^{1+2}: S^{1+2} segmentectomy; S^{1+2+3}: S^{1+2+3} segmentectomy.



Video 1: Total thoracoscopic S^{1+2} segmentectomy.

DISCUSSION

Thoracic surgeons occasionally doubt the need for lobectomy of small-sized lesions in the left upper lobe since it is one of the largest lobes. As a result, segmentectomy has been utilized as an alternative option to left upper lobectomy for lung cancer in the left upper lobe. It has been indicated that segmentectomy offers some advantages over lobectomy. In this study, postoperative lung function after thoracoscopic S^{1+2} segmentectomy was well-preserved and the preservable lung volume of the residual lobe was well-maintained compared to that after other types of thoracoscopic segmentectomies. Thus, in cases where the tumour is located in the apex of the left upper lobe and the tumour margin is sufficiently secured, postoperative lung function could best be preserved by using thoracoscopic S^{1+2} segmentectomy.

Whether segmentectomy offers postoperative clinical safety and benefit over lobectomy remains controversial. While several studies indicated that there was no difference of perioperative morbidity and mortality between segmentectomy and lobectomy [9, 10], less morbidity, better physical, emotional and cognitive functioning and less symptoms of dyspnoea and fatigue after segmentectomy have been documented [11]. In our cohort, left upper segmentectomy showed favourable postoperative outcomes and better postoperative pulmonary function as compared to left upper lobectomy, indicating that segmentectomy could provide perioperative clinical benefits over lobectomy in the left upper lobe.

Identifying the accurate bifurcation of B^{1+2}/B^3 and the intersegmental veins is the most important procedure for S^{1+2} segmentectomy. As mentioned in the literature, 3D-CT simulation could be a powerful tool to facilitate the accurate identification of these bronchus and intersegmental veins both preoperatively and intraoperatively [12, 13]. The preoperative determination of the pulmonary vessels and segmental bronchi branches, the anatomical intersegmental surface and a sufficient surgical margin from the tumour can be estimated by 3D-CT simulation, called 'virtual segmentectomy' [14]. In addition to preoperative simulation and guidance by virtual segmentectomy, 3D-CT reconstruction enables predicting the postoperative lung function by calculating each lobe's volume accurately [15]. Recently, preoperative measurement of low attenuation area using 3D-CT in patients with lung cancer, particularly with the coexistence of emphysema, was also beneficial for predicting postoperative respiratory complications including prolonged air leak [16]. Thus, 3D-CT simulation could be indispensable for lung cancer surgery.

Segmentectomy, such as S^{1+2+3} and S^{4+5} segmentectomies, could yield similar oncological outcomes to left upper lobectomy. The left upper lobe is divided in 2 anatomical units: upper division (segments 1 + 2 and 3) and lingula (segments 4 and 5). This division could be compared to the anatomy of the right upper lobe and middle lobe, as described elsewhere [17]. Although segmentectomies have usually been proposed for the treatment of NSCLC <2 cm with a general positive consensus, some reports have advocated that a 'Split lobectomy' (i.e. S^{1+2+3} and S^{4+5} segmentectomies) leads to similar oncological outcomes compared to left upper lobectomy; this was found even in patients with tumour diameter above 2 cm and a good pulmonary function in the left upper lobe [18, 19]. Thus, the split-lobe procedure could be an alternative to left upper lobectomy in select cases of left upper NSCLC if such procedures produce a sufficient tumour margin away from the intersegmental plane and a complete lymphadenectomy. Our team is also currently working on this clinical implementation, yet, it has not been clarified if S^{1+2} segmentectomy could also be an alternative to lobectomy. To support a translation of the split-lobe concept to S^{1+2} segmentectomy of left apical NSCLC, more patients must be studied over a longer time interval.

However, loco-regional recurrences after segmentectomy should be considered. Lobectomy has been reported to be superior to segmentectomy for securing adequate surgical margins, resulting in a lower rate of local-regional recurrence than segmentectomy [20]. According to Sienel *et al.* [21], segmentectomy in the S^{1+2+3} regions more frequently lead to local recurrence than segmentectomy in the remaining segments. In our previous report, while segmentectomies in the right upper lobe and basal segments showed significantly higher local recurrence than other segmentectomies, the left upper segmentectomy was not a significant risk factor for loco-regional recurrences [22]. Thus, left lobectomy or the additional neighbouring segment resection would be preferable if upper lobe lesions near the segmental border are predicted through preoperative 3D-CT virtual simulation.

One reason why S^{1+2} segmentectomy was preserved more than S^{1+2+3} segmentectomy was the upward displacement of the residual lobe after the removal of S^{1+2+3} segments. The anatomy of the left upper division (S^{1+2+3}) is similar to the right upper lobe, and it has been reported that the deviation of the right middle lobar bronchus affects the mechanism of pulmonary aeration after right upper lobectomy [23]. Nomori *et al.* [24] also demonstrated that S^{1+2+3} segmentectomy decreased lobar function significantly due to large resection and marked depression of the preserved lobe, resulting in a decrease similar to lobectomy using lung perfusion single-photon emission computed tomography. However, there have been no reports to date describing the comparison of S^{1+2} segmentectomy and other segmentectomies in terms of preserving postoperative pulmonary function. To our knowledge, this study is the first to elucidate the efficacy and superiority of S^{1+2} segmentectomy for preserving postoperative lung function.

Limitations

This study has some limitations. First, we only examined postoperative pulmonary function by calculating the lung volume and without evaluating the perfusion of the residual lobe. Additional modalities such as lung perfusion single-photon emission computed tomography are needed for this purpose. Second, we did not include other types of complicated segmentectomies such as S^3 segmentectomy since it has small number of cases. S^3 segmentectomy involves 2 intersegmental surfaces at an acute angle and requires technical acuity for identifying and dissecting true intersegmental plane. The utilization of Indocyanine green injection may help to identify demarcation line, contributing to increased cases of S^3 segmentectomy in the future. Third, postoperative spirometry was only examined 6 months after resection. Long-term changes, such as 1- or 3-year evaluation, should be performed to understand the chronological changes after segmentectomy.

CONCLUSION

In conclusion, although left S^{1+2+3} segmentectomy spared the lower residual lobe function more than was predicted preoperatively, segmentectomy preserved the whole lung function better than lobectomy. Moreover, postoperative lung function and the preservable lung volume of the residual lobe were best preserved after thoracoscopic S^{1+2} segmentectomy compared to those after other segmentectomies. Thus, in cases where the tumour is located in the apex of left upper lobe and the tumour margin is secured, thoracoscopic S^{1+2} segmentectomy could be a good alternative to preserve postoperative lung function.

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Author contributions

Shinya Tane: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Writing—original draft; Writing—review & editing. **Wataru Nishio:** Investigation; Writing—review & editing. **Yusuke Fujibayashi:** Writing—review & editing. **Megumi Nishikubo:** Writing—review & editing. **Yuki Nishioka:** Writing—review & editing. **Hiroyuki Ogawa:** Writing—review & editing. **Yoshitaka Kitamura:** Writing—review & editing. **Daisuke Takenaka:** Resources; Software. **Masahiro Yoshimura:** Writing—review & editing.

Reviewer information

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