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ORIGINAL ARTICLE

Comparison of surgical outcomes between thoracoscopic anatomical sublobar resection including and excluding subsegmentectomy

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Abstract

Objectives Despite the ubiquitous utilization of anatomical sublobar resection for malignant lung tumors, the effectiveness and feasibility of subsegmentectomy remains unclear. This study therefore compared the perioperative outcomes between anatomical sublobar resection including (IS) and excluding (ES) subsegmentectomy.

Methods Patients who had undergone anatomical sublobar resection at our institution from January 2013 to March 2019 were retrospectively reviewed. Clinicopathologic characteristics and perioperative outcomes of the IS group ($n = 58$) were then analyzed the compared to those of the ES group ($n = 203$).

Results No statistically significant differences in age, sex, comorbidities, tumor location, preoperative pulmonary function, or tumor size on imaging were found between both groups. The IS group had significantly higher preoperative computed tomography-guided marking rates (40% vs. 18%; $p < 0.01$) and used significantly more staplers for intersegmental dissection than the ES group [4, interquartile range (IQR): 3–4 vs. 3, IQR: 3–4; $p = 0.03$]. Both groups had comparable 30-day mortality (0% vs. 0%; $p > 0.99$), intraoperative complications (7% vs. 10%; $p = 0.61$), and postoperative complications (5% vs. 8%; $p = 0.58$). After propensity score matching, the IS group experienced significantly lesser blood loss than the ES group (5 mL, IQR: 1–10 vs. 5 mL, IQR: 5–20; $p = 0.03$). Both groups experienced no local recurrence and demonstrated similar postoperative pulmonary functions after surgery.

Conclusions IS may be a feasible and acceptable therapeutic option for malignant lung tumors. Nonetheless, future investigations are required to further validate the current findings.

Keywords Sublobar resection · Subsegment · Surgical outcome · Surgical margin · Pulmonary function

Abbreviations

CT	Computed tomography
ES	Anatomical sublobar resection excluding subsegmentectomy
FEV_1	Forced expiratory volume in 1.0 s
FVC	Forced vital capacity
IQR	Interquartile range
IS	Anatomical sublobar resection including subsegmentectomy
MRI	Magnetic resonance imaging
NSCLC	Non-small cell lung cancer
PET	Positron emission tomography

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Introduction

In 1995, the Lung Cancer Study Group reported that sublobar resection in stage IA non-small cell lung cancer (NSCLC) was associated with poorer overall survival and three times higher local recurrence rate compared to lobectomy [1]. Therefore, sublobar resection has been performed only for patients with NSCLC who cannot tolerate lobectomy. However, the recent wide use of high-resolution computed tomography (CT) in general practice has promoted increased early-stage detection of NSCLCs [2]. Furthermore, with societal aging and increased incidence of metastatic lung tumors, anatomical sublobar resection has become a common treatment option for pulmonary malignancies. Recent research has suggested that segmentectomy and lobectomy may have comparable prognosis for small-sized stage I NSCLC, even among those who cannot tolerate lobectomy [3–6]. Technical difficulties associated with anatomical sublobar resection can vary based on the vessels, bronchus, and lung parenchyma requiring surgically resection. With the recent advancements in surgical technique, anatomical sublobar resection including subsegmentectomy (IS) has gradually become widespread in some high-volume institutions [7–9]. IS may involve segmental and subsegmental resection or subsegmental resection alone. In all such cases, surgeons require precise techniques to identify and dissect the pulmonary arteries, veins, and bronchi within the subsegments. The current study focused on this surgical procedure given its technical difficulty and the lack of current investigations determining its feasibility. Thus, anatomical sublobar resection was subdivided into two procedures according to whether subsegment(s) were included in the resection area.

IS is technically more difficult compared to anatomical sublobar resection excluding subsegmentectomy (ES) and is often required for small-to-intermediate relatively deep pulmonary nodules. Concerns regarding the increased risk of morbidity and mortality due to the procedural complexity of IS have prevented surgeons from performing this procedure. However, despite its technical difficulty, IS is particularly helpful in securing appropriate surgical margins with minimal extent of lung resection in certain patients. Given the few reports documenting the clinical outcomes in the relatively small number of IS cases, appropriate indications for IS have remained unclear. Therefore, this study aimed to evaluate the perioperative outcomes and time-course changes in pulmonary function following IS and compare them to those following ES.

Subjects and methods

Study design and patients

This retrospective study was approved by the institutional review board of Aichi Cancer Center on 7th February, 2019 (approval number 2019-1-431). All anatomical sublobar resection cases among the 2452 patients who had undergone lung resection between January 2013 and March 2019 from our database were reviewed. The exclusion criteria were as follows: (a) patients who had undergone thoracotomy due to reduced pulmonary function, especially in the early postoperative period [10], (b) those who had undergone simultaneous resection in different lobes, and (c) those pathologically diagnosed with non-malignant disease. Indications for surgery were preoperatively established during our multidisciplinary tumor board meetings, after which written informed consent was obtained from the patient before surgery.

Patients were then divided into two groups: IS (i.e., anatomical sublobar resection including subsegmentectomy; $n = 58$) and ES (i.e., anatomical sublobar resection excluding subsegmentectomy; $n = 203$). The primary endpoints included operative time, blood loss, surgical margin distance, mortality, morbidity, length of hospital stay or drainage, and postoperative pulmonary function.

Preoperative evaluation

All patients underwent carefully evaluation using high-resolution CT, 18-fluorodeoxyglucose positron emission tomography CT (PET/CT), brain magnetic resonance imaging (MRI), biochemistry (including tumor markers), electrocardiography, echocardiography, and pulmonary function tests within 6 weeks before surgery. For patient with primary lung cancer, staging was determined according to the *Tumor, Nodes, and Metastasis Classification of Malignant Tumors,* eighth edition [11]. Patients were classified into curative and palliative indications based on the decision of the preoperative tumor board. Indications for curative group included NSCLC with a tumor diameter of ≤ 2 cm and a consolidation tumor ratio of ≤ 0.25 and patients who can tolerate lobectomy [6].

Surgical procedure and pathological specimens

Surgeries were performed by four experienced attending general thoracic surgeons exclusively under thoracoscopic view mainly using four ports. CT-guided marking with a mixture of lipiodol and indigo carmine was performed as necessary preoperatively (Supplementary Fig. 1) [12]. The bronchus, artery, and vein at the hilum were carefully isolated and dissected (Supplementary video 1). The intersegmental planes were often dissected using an endoscopic surgical stapler.

The surgical margin to the closest tumor edge on a collapsed lung was macroscopically measured after removing the parenchymal staples. If necessary, a frozen section of the surgical margin was evaluated under a microscope. The tumor was evaluated as positive when it reached the margin and close when the distance between the tumor and the margin was < 1000 μm. If possible, patients with a positive or close surgical margin underwent additional resection to secure the surgical margin.

Follow-up evaluation

Clinicopathological data were collected from the medical records. Perioperative complications were classified and graded according to the Common Terminology Criteria for Adverse Events version 5.0, subsequently analyzing all grade 2 (moderate) or higher complications [6]. Perioperative mortality was defined as death within 30 days after surgery. Patients were followed from the day of surgery and were examined at intervals of 3–6 months for the first 5 years and then once a year thereafter [13], typically involving physical examination, biochemistry (including tumor markers), chest-abdominal CT, and brain MRI. Pulmonary function was retested 6 and 12 months after surgery. Biopsy was performed for histological confirmation of local recurrence if necessary. Otherwise, radiological evidence of local recurrence, including PET/CT, was accepted by the institutional multidisciplinary tumor board.

Statistical analysis

Data were presented as numbers or median with interquartile range (IQR). Differences between IS and ES were evaluated using Fisher's exact test for categorical variables and the Mann–Whitney *U* test for continuous variables. Changes in pulmonary function were compared using repeated-measures analysis of variance, while time-dependent changes in the forced vital capacity (FVC) and forced expiratory volume in 1.0 s (FEV_1) were determined. Furthermore, propensity score matching was used to balance the number of eligible patients. Nearest-neighbor matching within a caliper was performed using a caliper width of 0.20. Accordingly, clinicopathological variables, such as age, sex, body mass index, year of surgery, smoking, cardiovascular dysfunction, pulmonary comorbidities, diabetes mellitus, renal dysfunction, preoperative pulmonary function, tumor location, induction therapy, resection volume (total number of subsegments), preoperative CT-guided marking, indication for sublobar resection, adjuvant therapy, and pathological diagnosis, were multiplied by a coefficient calculated using logistic regression analysis. The c-statistic value for this matching was 0.78. Patients with IS and ES who had equivalent propensity scores were then selected through 1–1 matching to better determine perioperative outcomes. All statistical analyses were performed using the JMP software program for Windows (version 13.0; SAS Institute, Cary, NC, USA). All p values were two-sided, with $p < 0.05$ indicating statistical significance.

Results

Patient selection and characteristics

A total of 337 patients who underwent anatomical sublobar resection at our institution were analyzed (Fig. 1). Patients who underwent thoracotomy ($n = 51$) and simultaneous resection in different lobes ($n = 14$) and those with pathologically proven non-malignant diseases ($n = 11$) were excluded. The final study cohort comprised 261 patients who underwent thoracoscopic anatomical sublobar resection for the treatment of lung malignancies, among whom 58 were in the IS group and 203 were in the ES group. The median follow-up period was 37 and 36 months in the IS and ES groups, respectively. Table 1 summarizes the patient characteristics of both groups. Primary lung cancer was the most common pathological diagnosis (IS: $n = 42$, 72%; ES: $n = 159$, 78%), followed by metastatic lung cancer (IS: $n = 16$, 28%; ES: $n = 40$, 20%). No statistically significant differences in age, sex, comorbidities, tumor location, preoperative pulmonary function, tumor size on imaging, and pathological diagnosis were found. However, the IS group utilized preoperative CT-guided marking ($n = 23$, 40%) more frequently than the ES group ($n = 36$, 18%) ($p < 0.01$).

Factors related to surgery

Figure 2 shows the actual resected lung segment(s) and subsegment(s) in both groups. In the IS group, the left and right superior segments (S6) and left upper division were frequently involved. In the ES group, the left upper division was the most commonly involved ($n = 30$, 15%), followed by the left apical segment (S1 + 2: $n = 28$, 14%) and right superior segment (S6: $n = 24$, 12%). As shown in Table 1, no significant differences in operative time (182 min, IQR: 153–215 vs. 181 min, IQR: 152–216; $p = 0.88$) and blood loss (5 mL, IQR: 1–10 vs. 5 mL, IQR: 1–20; $p = 0.14$), as well as median surgical margin distance (20 mm, IQR: 15–20 vs. 20 mm, IQR: 20–20; $p = 0.86$) were observed between both groups. The ES group had 2 (1%) and 6 (3%) cases with a positive and close surgical margin, whereas the IS group had none and only 1 (2%) case with a positive and close surgical margin, respectively ($p > 0.99$). Accordingly, 5 (2%) ES cases and 4 (7%) IS cases underwent additional resection based on intraoperative evaluation of surgical margins ($p = 0.11$). The IS group needed significantly more endoscopic surgical staples for intersegmental plane dissection (4, IQR: 3–4) than the ES group (3, IQR; 3–4) ($p = 0.03$). No perioperative deaths occurred in either group, while

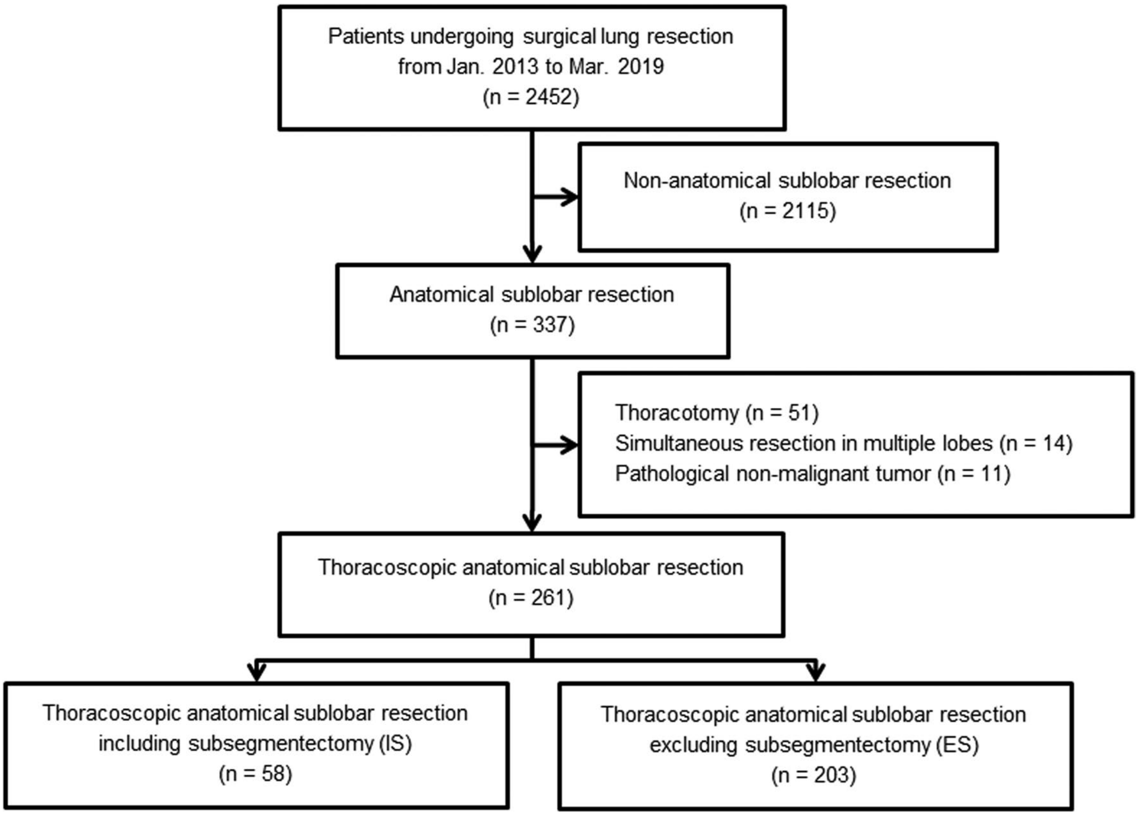


Fig. 1 Flow chart for patient selection

no significant differences in length of hospital stay (3 days, IQR: 3–5 vs. 3 days, IQR: 3–5, $p=0.91$) or length of drainage (0 days, IQR: 0–1 vs. 0 days, IQR: 0–1; $p=0.44$) were observed between the groups. However, propensity score-matched pair analysis showed that the IS group had significantly lower blood loss (5 mL, IQR: 1–10) than the ES group (5 mL, IQR: 5–20) ($p=0.03$). Finally, no local recurrences occurred in both groups during the research period.

Complications

Table 2 details the intraoperative and postoperative complications in both groups. Accordingly, the IS group developed 4 (7%) intraoperative complications and 3 (5%) postoperative complications. All intraoperative complications in the IS group were pulmonary artery injuries, including those with minimal bleeding. No statistically significant differences in intraoperative (7% vs. 10%; $p=0.61$) and postoperative complications (5% vs. 8%; $p=0.58$) were observed between both groups, with propensity score-matched pair analysis showing similar findings.

Pulmonary function changes

Preoperative and postoperative pulmonary function test results were available in 173 (66%) patients. Moreover, cases requiring conversion to thoracotomy in both groups were excluded from pulmonary function analysis. During the postoperative course, both groups showed comparable pulmonary function without a significant difference in ratio of postoperative-to-preoperative FVC ($p=0.54$; Fig. 3a) and FEV_1 ($p=0.37$; Fig. 3b). Propensity score-matching analysis also showed findings consistent with the original data in both FVC ($p=0.71$; Fig. 3c) and FEV_1 ($p=0.56$; Fig. 3d).

Discussion

This retrospective study analyzed the surgical and postoperative outcomes of patients who underwent IS and ES. The current findings demonstrated no significant difference in operative time, blood loss, perioperative complications, and postoperative pulmonary functions between both groups. Furthermore, no local recurrence was observed in both groups during the research period.

Table 1 Clinicopathological factors of thoracoscopic anatomical sublobar resection including and excluding subsegmentectomy

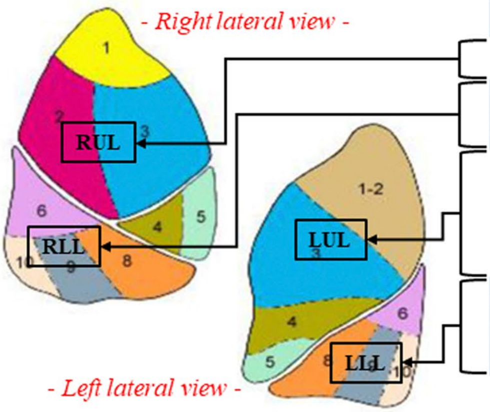
Variables	All patients (*n* = 261)			Propensity score-matched pairs (*n* = 90)		
	IS (*n* = 58)	ES (*n* = 203)	*p* value	IS (*n* = 45)	ES (*n* = 45)	*p* value
Age, years	70 (62–76)	69 (61–75)	0.51	69 (62–75)	69 (60–78)	0.9
Sex, female	28 (48)	113 (56)	0.37	23 (51)	26 (58)	0.67
Body mass index	22 (20–24)	22 (20–25)	0.61	22 (20–24)	22 (20–25)	0.71
Smoking, never	25 (43)	106 (52)	0.24	21 (47)	24 (53)	0.67
Tumor location						
Right upper lobe	11 (19)	50 (25)	0.24	8 (18)	7 (15)	0.98
Right lower lobe	9 (15)	43 (21)		9 (20)	9 (20)	
Left upper lobe	22 (38)	77 (38)		17 (38)	16 (36)	
Left lower lobe	16 (28)	33 (16)		11 (24)	13 (29)	
Comorbidities						
COPD/interstitial pneumonitis	1 (2)	18 (9)	0.08	1 (2)	2 (4)	> 0.99
Diabetes mellitus	8 (14)	34 (17)	0.69	7 (15)	7 (15)	> 0.99
Cardiovascular dysfunction	26 (45)	91 (45)	> 0.99	19 (42)	23 (51)	0.53
Renal dysfunction	4 (7)	15 (7)	> 0.99	3 (7)	6 (13)	0.48
Pulmonary function						
Forced vital capacity, L	2.87 (2.46–3.21)	2.97 (2.48–3.65)	0.39	2.89 (2.47–3.24)	2.74 (2.36–3.48)	0.57
Forced expiratory volume in 1.0 s, L	2.07 (1.75–2.70)	2.21 (1.82–2.64)	0.39	2.13 (1.86–2.71)	2.02 (1.81–2.76)	0.83
Tumor size on CT, mm	16 (11–21)	17 (13–23)	0.3	16 (12–21)	17 (12–22)	0.57
Solid component size on CT, mm	9 (6–15)	10 (6–17)	0.37	8 (7–14)	8 (5–12)	0.58
Pathological diagnosis						
Primary lung cancer	42 (72)	159 (78)	0.33	32 (71)	36 (80)	0.46
Metastatic lung cancer	16 (28)	40 (20)		13 (29)	9 (20)	
Recurrent lung cancer	0 (0)	4 (2)		0 (0)	0 (0)	
Pathological tumor size, mm	14 (11–18)	15 (11–21)	0.18	14 (11–17)	13 (10–19)	0.95
Preoperative CT-guided marking	23 (40)	36 (18)	< 0.01	17 (38)	14 (31)	0.66
Any preoperative therapy	3 (5)	14 (7)	0.77	3 (7)	2 (4)	> 0.99
Indication of sublobar resection						
Palliative	44 (76)	140 (69)	0.33	33 (73)	28 (62)	0.37
Curative	14 (24)	63 (31)		12 (27)	17 (38)	
Operative outcomes						
Operative time, min	182 (153–215)	181 (152–216)	0.88	181 (152–212)	178 (157–218)	0.66
Blood loss, mL	5 (1–10)	5 (1–20)	0.14	5 (1–10)	5 (5–20)	0.03
Conversion to thoracotomy	1 (2)	1 (1)	0.4	1 (2)	0 (0)	> 0.99
Number of dissected subsegments	3 (2–4)	3 (2–4)	0.35	3 (2–4)	3 (2–4)	0.72
Surgical margin distance, mm	20 (15–20)	20 (20–20)	0.86	20 (20–20)	20 (20–20)	0.97
Surgical margin assessment						
Negative	57 (98)	195 (96)	> 0.99	44 (98)	43 (96)	> 0.99
Close	1 (2)	6 (3)		1 (2)	1 (2)	
Positive	0 (0)	2 (1)		0 (0)	1 (2)	
Additional surgical margin resection	4 (7)	5 (2)	0.11	4 (9)	0 (0)	0.12
Number of dissected lymph nodes	2 (1–3)	2 (1–5)	0.08	1 (1–3)	2 (1–4)	0.39
Number of dissected lymph-node sites	1 (1–2)	2 (1–3)	0.05	1 (1–2)	2 (1–3)	0.24
Number of staples[a]	4 (3–4)	3 (3–4)	0.03	4 (3–4)	3 (3–4)	0.17
Postoperative outcomes						
Length of hospital stay, days	3 (3–5)	3 (3–5)	0.91	3 (3–5)	4 (3–5)	0.76
Length of drainage, days	0 (0–1)	0 (0–1)	0.44	0 (0–1)	0 (0–1)	0.37
Drain removal on the operative day	36 (62)	114 (56)	0.45	29 (64)	26 (58)	0.67
Mortality (30-day)	0 (0)	0 (0)	> 0.99	0 (0)	0 (0)	> 0.99
Local recurrence on surgical margin	0 (0)	0 (0)	> 0.99	0 (0)	0 (0)	> 0.99

Values are presented as median (interquartile range) or *n* (%)

COPD chronic obstructive pulmonary disease, *CT* computed tomography, *ES* anatomical sublobar resection excluding subsegmentectomy, *IS* anatomical sublobar resection including subsegmentectomy

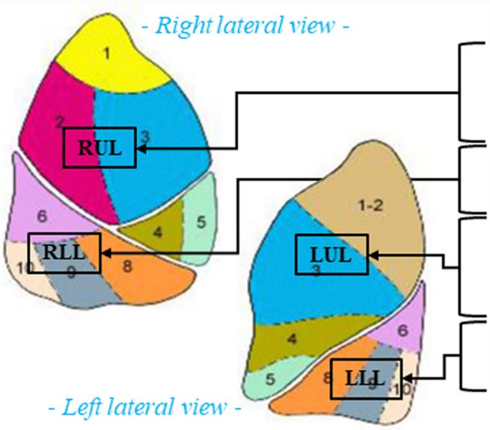
[a]Number of staples for intersegmental formation

Resected areas for thoracoscopic anatomical sublobar resection including subsegmentectomy (IS; n = 58)



Tumor location lobe	n (%)	Details of resected site	n (%)
Right upper lobe	2 (3)	Subsegment 2b and 3a	2 (3)
Right lower lobe	4 (6)	Segment 6 and 8a Segment 6 and 10a	2 (3) 2 (3)
Left upper lobe	8 (12)	Segment 1+2 and 3a Segment 1+2 and 3c Segment 3 and 1+2a Subsegment 1+2a and 3c	2 (3) 2 (3) 2 (3) 2 (3)
Left lower lobe	7 (11)	Segment 6 and 8a Segment 6 and 10a Segment 10 and 6c	2 (3) 3 (5) 2 (3)
…..	37 (68)	Others	37 (68)

Resected areas for thoracoscopic anatomical sublobar resection excluding subsegmentectomy (ES; n = 203)



Tumor location lobe	n (%)	Details of resected site	n (%)
Right upper lobe	43 (21)	Segment 1 Segment 2 Segment 3	10 (5) 17 (8) 16 (8)
Right lower lobe	30 (15)	Segment 6 Segment 10	24 (12) 6 (3)
Left upper lobe	71 (35)	Segment 1+2 Upper division Lingula	28 (14) 30 (15) 13 (6)
Left lower lobe	22 (10)	Segment 6 Segment 9 and 10	15 (7) 7 (3)
…..	37 (19)	Others	37 (19)

Fig. 2 Resected areas for thoracoscopic anatomical sublobar resection including (IS) and excluding (ES) subsegmentectomy. Top 10 most frequently resected areas and others in the IS or ES group

In a study by Nakamoto et al. [7], 23 patients who had undergone IS experienced no postoperative complications and had a 5-year disease-free survival rate of 100%. Yoshimoto and colleagues [8] also documented that subsegmentectomy promoted significantly superior FEV_1 compared to segmentectomy. However, perioperative complications and change in pulmonary function have still remained unclear considering the few studies investigating clinical outcomes following IS.

The absence of significant differences in surgical outcomes and complications between the IS and ES group is clinically significant and novel. Furthermore, propensity score-matched pair analysis showed that the IS group had significantly less bleeding than the ES group. We believe the present findings carry value given our expectation that the procedural complexity of IS would promote increased operative times and perioperative complications. In fact, IS had a tendency to more easily injure the pulmonary artery than ES, although repairs could be completed easily and quickly given that all injured arteries were small subsegmental branches. The ease of dealing with vascular injuries during IS may have produced unexpectedly favorable surgical outcomes.

The IS group more frequently utilized preoperative CT-guided marking with lipiodol and indigo carmine than the ES group considering that lung tumors in the IS group were closer to the intersegmental planes and deeper in the lung parenchyma than those in the ES group. The CT-guided marking helped to ensure appropriate surgical margin distances. We had previously reported that pulmonary nodule localization with lipiodol and indigo carmine marking was safe and effective for small-sized pulmonary nodules [12]. The present study suggested that pulmonary nodule

Table 2 Complications of thoracoscopic anatomical sublobar resection including and excluding subsegmentectomy

Variables	All patients ($n=261$)			Propensity score-matched pairs ($n=90$)		
	IS ($n=58$)	ES ($n=203$)	p value	IS ($n=45$)	ES ($n=45$)	p value
Intraoperative complications						
Any complication (grade ≥ 2)	4 (7)	20 (10)	0.61	4 (9)	4 (9)	> 0.99
Any organ injury	4 (7)	17 (8)	> 0.99	4 (9)	4 (9)	> 0.99
Aorta	0 (0)	1 (1)	> 0.99	0 (0)	0 (0)	> 0.99
Pulmonary artery	4 (7)	7 (3)	0.27	4 (9)	1 (2)	0.36
Pulmonary vein	0 (0)	2 (1)	> 0.99	0 (0)	0 (0)	> 0.99
Bronchus	0 (0)	2 (1)	> 0.99	0 (0)	1 (2)	> 0.99
Phrenic nerve	0 (0)	1 (1)	> 0.99	0 (0)	1 (2)	> 0.99
Recurrent nerve	0 (0)	1 (1)	> 0.99	0 (0)	0 (0)	> 0.99
Atelectasis	0 (0)	3 (1)	> 0.99	0 (0)	1 (2)	> 0.99
Anatomical misidentification	0 (0)	3 (1)	> 0.99	0 (0)	0 (0)	> 0.99
Postoperative complications						
Any complication (grade ≥ 2)	3 (5)	16 (8)	0.58	3 (7)	2 (4)	> 0.99
Air leak (> 5 days)	1 (2)	3 (1)	> 0.99	1 (2)	1 (2)	> 0.99
Respiratory disorder	0 (0)	3 (1)	> 0.99	0 (0)	0 (0)	> 0.99
Effusion	0 (0)	3 (1)	> 0.99	0 (0)	1 (2)	> 0.99
Secondary pneumothorax	0 (0)	1 (0)	> 0.99	0 (0)	0 (0)	> 0.99
Atelectasis	0 (0)	1 (0)	> 0.99	0 (0)	0 (0)	> 0.99
Acute exacerbation of IP	0 (0)	1 (1)	> 0.99	0 (0)	0 (0)	> 0.99
Intrathoracic bleeding	0 (0)	1 (1)	> 0.99	0 (0)	0 (0)	> 0.99
Wound infection	1 (2)	2 (1)	0.53	1 (2)	0 (0)	> 0.99
Atrial fibrillation	1 (2)	0 (0)	0.22	1 (2)	0 (0)	> 0.99
Pseudomembranous colitis	0 (0)	2 (1)	> 0.99	0 (0)	0 (0)	> 0.99
Hepatic dysfunction	0 (0)	1 (1)	> 0.99	0 (0)	0 (0)	> 0.99
Chronic pain	0 (0)	1 (1)	> 0.99	0 (0)	0 (0)	> 0.99

Values are presented as n (%)

ES anatomical sublobar resection excluding subsegmentectomy, *IP* interstitial pneumonitis, *IS* anatomical sublobar resection including subsegmentectomy

localization may have been among the reasons why the IS group had better surgical outcomes compared to the ES group.

IS has a more complicated intersegmental plane compared to ES, which may disturb remnant lung expansion and reduce postoperative pulmonary function, especially during the early postoperative period. Previous reports have demonstrated that anatomical sublobar resection better preserved postoperative pulmonary function compared to lobectomy, although such reports had mainly employed ES for analyses [14, 15]. The present findings showed that both IS and ES had similarly preserved postoperative pulmonary functions. However, intersegmental formations using automatic suturing devices may have affected changes in postoperative pulmonary function in both groups.

Previous reports had demonstrated that ensuring sufficient surgical margin distance was important for preventing local recurrence [16], the risk of which was significantly increased with surgical margin distances < 10 mm [17]. Furthermore, a previous multicenter prospective study suggested that a surgical margin distance greater than the tumor diameter was optimal for local recurrence prevention [18]. In the IS group, the median surgical margin (20 mm) was significantly greater than the median tumor diameter (14 mm), with no positive malignant cells on the surgical margin. Although no cases experienced local recurrence throughout the study period, further analysis of survival outcomes is required to establish more convincing data.

Several limitations of the present study should be noted. First, this was a single-center retrospective study with a relatively small number patients. Second, the total number of subsegments was used to match the resected lung volume in both groups. Pre- and postoperative three-dimensional lung imaging with volumetry may help to provide more detailed information. Third, postoperative pulmonary function tests, particularly diffusion capacity for carbon monoxide, could not be performed in some cases. Fourth, survival analysis

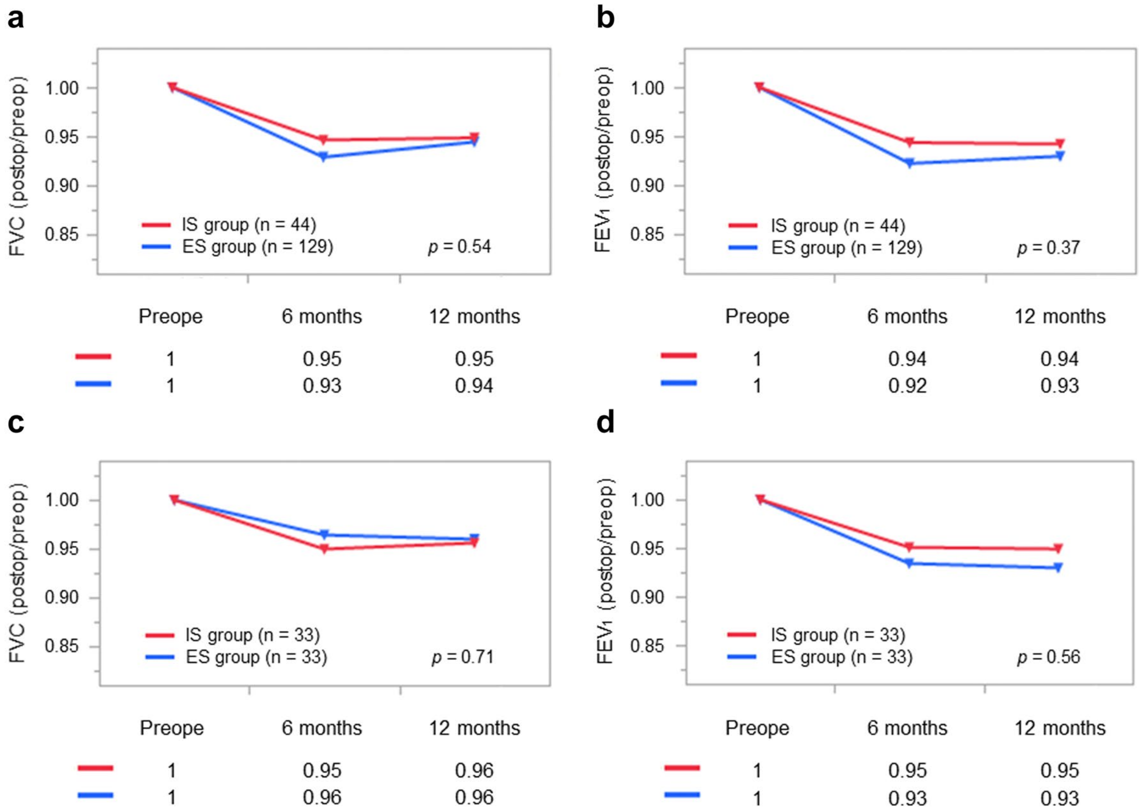


Fig. 3 Changes in forced vital capacity (FVC) and forced expiratory volume in 1.0 s (FEV_1) following thoracoscopic anatomical sublobar resection including (IS) and excluding (ES) subsegmentectomy at 6 and 12 months after surgery. The *y*-axis shows the postoperative-to-preoperative ratio (postop/preop). Changes in FVC and FEV_1 in all patients (**a**, **b**) and propensity score-matched pairs (**c**, **d**) [IS group (red), ES group (blue)]

could not be performed due to insufficient follow-up period in most cases.

Conclusion

The current study suggests that IS may be an acceptable treatment option for malignant lung tumors, with surgical outcomes comparable to those of ES. Future multicenter prospective studies on IS that investigate long-term local recurrence-free and overall survival rates are nonetheless needed.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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