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ORIGINAL ARTICLE

Influence of intersegmental plane size and segment division methods on preserved lung volume and function after pulmonary segmentectomy

Hiroyuki Tao[1,2] · Masataro Hayashi[2] · Masashi Furukawa[2] · Ryohei Miyazaki[2] · Shintaro Yokoyama[2] · Akio Hara[2] · Kazunori Okabe[2]

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Abstract

Objectives We previously reported that the use of a stapler to divide intersegmental planes did not decrease preserved pulmonary volume or function relative to electrocautery. However, preservation of pulmonary volume or function can be compromised when a stapler is used with larger intersegmental planes. Here, we assessed the correlations between preserved lung volume and pulmonary function after segmentectomy and the size of the intersegmental planes, based on the division method.

Methods Intersegmental plane sizes in 56 patients were semi-automatically calculated using image analysis software on computed tomography images. The ratios of the remnant segment and ipsilateral lung volumes to their preoperative values (R-seg and R-ips) and the ratio of the postoperative pulmonary function relative to the predicted value were calculated based on three-dimensional volumetry. Correlations between preserved lung volume and pulmonary function and the intersegmental plane sizes were analyzed according to the division method.

Results Intersegmental planes were divided by either electrocautery or with a stapler (EC/Mixed) in 21 patients and by stapler alone (ST) in 35 patients. There was no difference in the average size of the intersegmental planes between the two groups. The intersegmental plane size negatively correlated with R-seg in the ST group.

Conclusions Using the stapler method, as the size of the intersegmental planes increased, the preserved remnant segmental volume decreased; however, relation between the plane size and preserved pulmonary function was unclear. These findings indicate that stapler use is acceptable even for large intersegmental planes.

Keywords Segmentectomy · Intersegmental plane · Pulmonary function · Computed tomography

Introduction

Preserving pulmonary function and obtaining adequate tumor margins are important goals of intersegmental lung division during pulmonary segmentectomy. Electrocautery, stapler, or a combination of both are used to divide the intersegmental planes [1]. Electrocautery can theoretically divide the intersegmental planes as they are, as determined by inflation–deflation lines or by intravenous injection of indocyanine green [2]. Stapler use can interfere with lung expansion due to fixation of the visceral pleura to the staple line [3]. Therefore, electrocautery is thought to be a better technique for obtaining clean tumor margins and preserving pulmonary function. However, several clinical reports [4, 5] have shown contradictory effects of the two division methods on preservation of pulmonary function.

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✉ Hiroyuki Tao
htao@hrc-hp.com

[1] Department of Thoracic Surgery, Japanese Red Cross Society Himeji Hospital, 1-12-1 Shimoteno, Himeji 670-8540, Japan

[2] Division of Thoracic Surgery, Department of Surgery, National Hospital Organization Yamaguchi-Ube Medical Center, Ube, Japan

We previously examined pre- and post-segmentectomy lung volumes and pulmonary function using three-dimensional volumetry (3D-volumetry) and found that dividing the intersegmental planes by stapler did not decrease the preserved volume or function compared to dividing the planes by electrocautery alone or by mixed use of electrocautery and stapler [6]. Stapling is a fast and easy division method and is superior to electrocautery in controlling bleeding and preventing air leaks. Given that staplers do not sacrifice pulmonary preservation, they may be a better choice for division of the intersegmental planes.

Following stapler division of the intersegmental plane, the visceral pleura may be drawn into the staple line, interfering with expansion of the remnant lung in the immediate postoperative period [7]. This complication may be more pronounced when a stapler is applied to larger intersegmental planes. We thus examined the impact of intersegmental plane size on preserved pulmonary function after segmentectomy according to the division methods. We also examined that on preserved lung volume.

Materials and methods

Patients and surgical procedure

The institutional review board approved the study protocol (approved ID:YUMC 29-11). Written informed consent was obtained from each patient.

A total of 56 patients who underwent anatomic segmentectomy in our hospital from September 2011 to July 2016 were enrolled in the study. Preoperative diagnoses were as follows: clinical stage I primary lung cancer in 49 patients, metastatic lung cancer in 4 patients, non-tuberculous mycobacterial infection in 2 patients, and bronchial ectasia in one patient. Operations were done by video-assisted thoracoscopic surgery (VATS) through a mini-thoracotomy (3–6 cm skin incision) with 2 or 3 ports in 54 patients and by open thoracotomy in 2 patients. Patients who underwent postoperative radiotherapy to the thoracic cavity or additional lung resection were excluded. The segmentectomy procedure used in this study has been reported previously [6]. Briefly, we determined the intersegmental planes by creating inflation–deflation lines using high-frequency jet ventilation through fiberoptic bronchoscopy. Electrocautery, stapler, or both were used to divide the intersegmental planes according to the surgeon's discretion. If both methods were employed, electrocautery was first used peripherally, and then the stapler was used for the deep parenchyma. After electrocautery, the bare surface of the remnant segment was covered with a fibrin sealant with an absorbable polyglycolic acid felt (Neoveil; Japan Medical Planning Co, Kyoto, Japan).

Three-dimensional computed tomography

CT scans were performed using a 64-row multidetector CT scanner (Aquilion 64, Toshiba Medical, Japan) within 2 weeks before surgery and 6–12 months after surgery. Using 2-mm thick slices, thin-section images for 3D-CT were reconstructed. The following parameters were semi-automatically measured by selecting the corresponding bronchus, using image analysis software [8, 9] (Synapse Vincent ver. 4.4, Fujifilm Medical, Tokyo, Japan):

$$\text{Volume A} = \text{The volume of segment to be removed on preoperative CT,}$$

$$\text{Volume B} = \text{The volume of segment to be preserved on preoperative CT,}$$

$$\text{Volume C} = \text{The volume of intact lobe(s) on preoperative CT,}$$

$$\text{Volume B}' = \text{The volume of remnant segment on postoperative CT,}$$

$$\text{Volume C}' = \text{The volume of intact lobe(s) on postoperative CT.}$$

Actual/predicted volume ratios of preserved segment (R-seg) and ipsilateral lung (R-ips) were calculated using the following equations:

$$\text{R} - \text{seg} = \text{Volume B}'/\text{Volume B} \times 100(\%),$$

$$\text{R} - \text{ips} = \left(\text{Volume B}' + \text{Volume C}'\right)/(\text{Volume B} + \text{Volume C}) \times 100(\%).$$

Intersegmental plane size was also semi-automatically measured by selecting the corresponding bronchus in each case (Supplementary Material, Fig. S1).

Spirometry

Forced expiratory volume in 1 s (FEV_1) and forced vital capacity (FVC) were measured by spirometry within 2 weeks before surgery. Based on 3D-volumetry values, postoperative pulmonary function was predicted using the following equations [10]:

$$FEV_{1ppo} = FEV_1(\text{total lung volume} - \text{Volume A})/\text{total lung volume},$$

$$FVC_{ppo} = FVC(\text{total lung volume} - \text{Volume A})/\text{total lung volume}.$$

Postoperative spirometry was conducted at the same time as the postoperative CT. The ratios of postoperative actual FEV_1 (FEV_{1post}) and FVC (FVC_{post}) relative to their previously predicted values were calculated using the following equations:

$$R - FEV_1 = FEV_{1post}/FEV_{1ppo} \times 100(\%),$$

$$R - FVC = FVC_{post}/FVC_{ppo} \times 100(\%).$$

Statistics

Relationships between division methods and clinical factors were analyzed using the chi-square test for independent variables and Fisher's exact probability test if required. Student's *t* test and Mann–Whitney *U* test were used for continuous variables. Comparisons of the actual/predicted ratio of remnant lung volume (R-seg, R-ips) and preserved pulmonary function (R-FEV1, R-FVC) were made between the two division methods and were analyzed using the two-sample Student's *t* test. Linear regression analysis was used to test the relationship between the postoperative actual pulmonary function (FEV_1 and FVC) and the predicted values for each division method. Relationships between the size of the intersegmental planes and preserved lung volume or pulmonary function were also examined. All tests of significance were two-sided, and *P* values less than 0.05 were considered statistically significant. All data were analyzed using IBM SPSS Statistics for Windows (version 24.0; IBM Corp., Armonk, NY, USA).

Results

Types of segmentectomy by division methods are summarized in Fig. 1. Divided intersegmental planes were single (e.g. S6 segmentectomy) in 18 patients (simple-type segmentectomy) and were multiple (e.g. S9 + 10 segmentectomy) in 3 patients (complicated type segmentectomy). Division of intersegmental planes were done by electrocautery alone ($n = 5$) or by mixed use of electrocautery and stapler ($n = 16$) (EC/Mixed) in 21 patients and by stapler alone (ST) in 35 patients. Follow-up CT scans were taken 6.7 (median: 6, range: 5–12) months postoperatively. Mean intersegmental plane size was 85.7 (median: 83.2, range: 38.6–203.1) cm^2. There were no clinical differences between patients in the two division groups, including intersegmental plane size (Table 1). Mean values of R-seg and R-ips were 83.2% (median: 80.5, range: 37.9–140.2) and 106.0% (median: 103.9, range: 77.5–127.1), respectively. Mean values of R-FEV_1 and R-FVC were 103.5% (median: 103.9, range: 83.7–135.1) and 103.7% (median: 106.3, range: 79.4–125.1), respectively. There was no correlation of the actual/predicted ratio of remnant lung volume and pulmonary function with either division method (Table 2). In both division methods, FEV_{1post} and FVC_{post} correlated with FEV_{1ppo} and FVC_{ppo}, respectively (Table 3). Regarding correlation of the size of the intersegmental planes with the actual/predicted ratio of remnant lung volume, only in the ST group intersegmental plane size negatively correlated with R-seg (Fig. 2). No correlation between the size of the intersegmental planes and the actual/predicted ratio of pulmonary function was observed in either group.

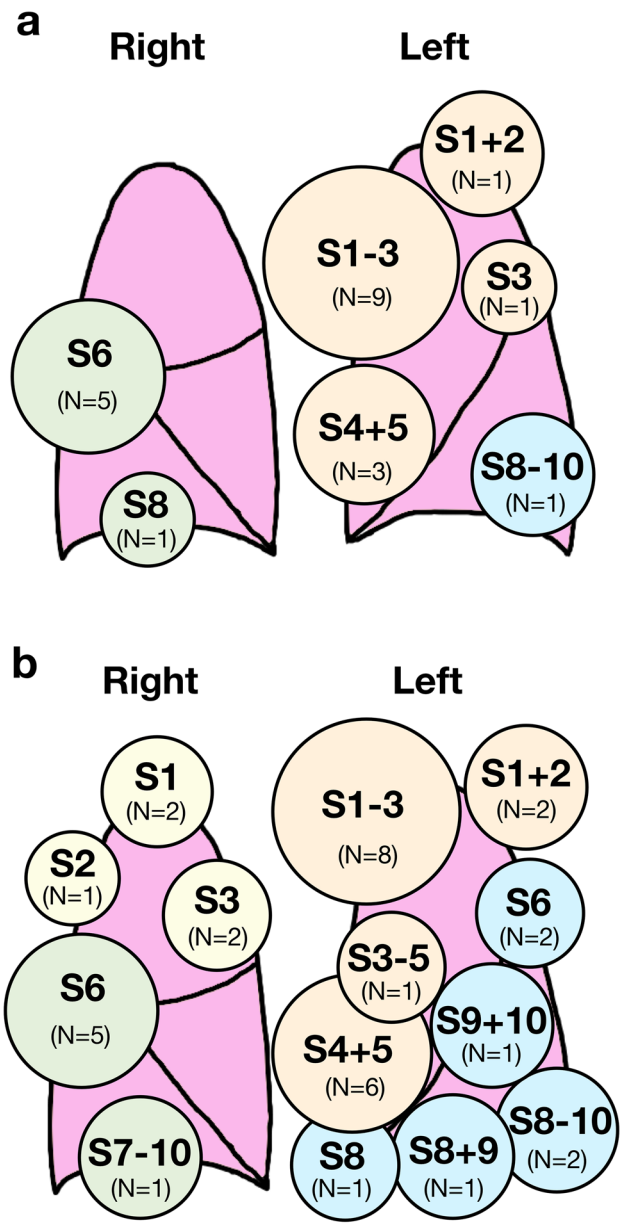

Fig. 1 Type of segmentectomy in the EC/Mixed group (**a**) and in the ST group (**b**)

Discussion

In this study, we found that when intersegmental planes were divided by the stapler method, the preserved remnant segmental volume decreased as the size of the planes

Table 1 Demographics

Demographic variable	EC/Mixed ($n=21$), %	ST ($n=35$), %	P value
Age	66.8 (SD:8.6)	65.6 (SD:13.9)	0.77[a]
Gender			
Female	13 (62)	14 (40)	–
Male	8 (38)	21 (60)	0.11
Location			
Upper lobe	14 (67)	22 (63)	–
Lower lobe	7 (33)	13 (37)	0.77
Removed segment			
Single	7 (33)	13 (37)	–
Multiple	14 (67)	22 (63)	0.77
%VC	100.5 (SD:14.6)	94.8 (SD:16.5)	0.19[b]
FEV1%	75.7 (SD:8.1)	75.0 (SD:1.6)	0.80[b]
Emphysematous change on HRCT			
Yes	2 (10)	8 (23)	–
No	19 (90)	27 (77)	0.29
Intersegmental			
Plane size (cm^2)	86.6 (SD:41.2)	85.2 (SD:24.8)	0.44[a]
Thoracic drainage (days)	4.7 (SD:4.0)	4.2 (SD:6.2)	0.20[a]

Continuous data are presented as mean (standard deviation), and categoric data are presented as number (%)

SD standard deviation, *VC* vital capacity, FEV_1 forced expiratory volume in 1 s, *HRCT* high-resolution computed tomography

[a]Mann–Whitney *U* test

[b]Student's *t* test

Table 2 Preserved lung volume and pulmonary function by division methods

Variable	EC/Mixed ($n=21$)	ST ($n=35$)	P value
R-seg	86.5 (SD:25.0)	81.2 (SD:25.4)	0. 45
R-ips	105.3 (SD:13.3)	106.5 (SD:12.6)	0.74
R-FEV1	101.9 (SD:8.7)	104.5 (SD:10.3)	0.33
R-FVC	102.4 (SD:9.1)	104.4 (SD:10.9)	0.48

SD standard deviation, *EC* electrocautery, *ST* stapler

Table 3 Correlation of postoperative actual pulmonary function with those predicted values by division methods

Methods	Linear correlation	R^2 value	P value
EC/Mixed ($n=21$)	$FEV_{1post}=0.82\times FEV_{1ppo}+0.36$	0.94	<0.001
	$FVC_{post}=0.90\times FEV_{1ppo}+0.30$	0.89	<0.001
ST ($n=35$)	$FEV_{1post}=0.90\times FEV_{1ppo}+0.28$	0.89	<0.001
	$FVC_{post}=0.97\times FEV_{1ppo}+0.19$	0.82	<0.001

EC electrocautery, *ST* stapler

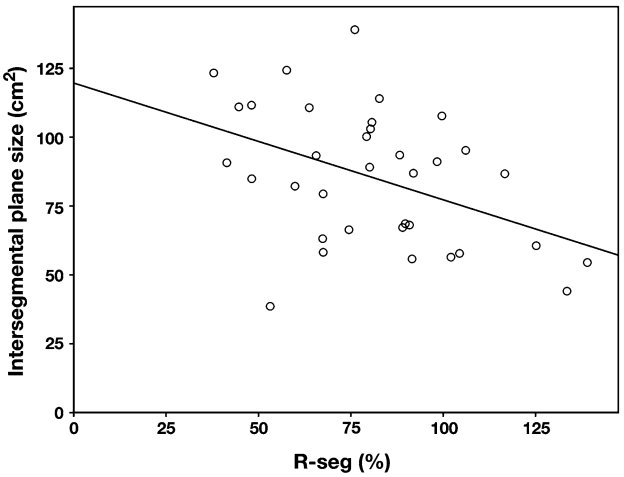

Fig. 2 Linear dependence between intersegmental plane size and the actual/predicted ratio of preserved segmental volume (R-seg) in the ST group ($Y=120-0.42X$, $R^2=0.19$, $P<0.01$)

increased. On the other hand, relation of the actual/predicted ratios of postoperative pulmonary function (R-FEV_1 and R-FVC) with the size of the intersegmental planes was unclear. It is possible that the remnant ipsilateral lobe compensated for lost volume and function in the stapled segment.

Although our findings indicate that division of the intersegmental planes by the stapler method preserves

residual pulmonary function likewise by the electrocautery method, the method has several technical difficulties. For example, stapler use in patients with thick, hard pulmonary parenchyma, especially patients with interstitial lung disease, can be difficult. The direction of stapler insertion can be limited, particularly in minimally invasive or reduced port surgery. In addition, adverse events related to stapler use can occur. Yano and colleagues examined over 10,000 stapling events and reported that adverse events, such as staple failure or laceration of the adjacent lung tissue, occurred in 0.74% [11]. They argued that stapler–tissue thickness mismatch and tissue fragility were major causes of adverse events. Functional improvements of the mechanical stapler will continue; at the same time, we must keep up detailed knowledge of its use.

This study has several limitations. We analyzed a small-sized group that underwent various kinds of segmentectomy. Division methods were determined by each surgeon's discretion, which could be associated with potential bias. For example, stapler use was favored for patients with emphysematous or fibrotic lung, though statistical difference was not shown in this study. Further studies based on a large-scale cohort are needed. As we mentioned in the previous report [6], morphological change of the remnant lung would have substantial influence on outcomes. Morphological change would be prominent when a stapler is employed in the division of multiple planes. In the current analysis, most of the operation was simple-type segmentectomy; only a right S8, a left S3 and a left S9 + 10 segmentectomies were included as multiple-plane division and stapler was employed only for a left S9 + 10 segmentectomy. Hence strictly speaking, the influence of stapler use and intersegmental plane size on the multiple planes remains unclear. In addition, since our previous analysis, we have primarily used the stapler method to divide the intersegmental planes. Therefore, the number of patients in the ST group increased while the number in the EC/Mixed group did not. It is possible that our results would have differed if we had more experience with the electrocautery method.

Conclusion

In conclusion, the size of the intersegmental planes negatively affected preserved segmental volume when a stapler was used to divide the planes during pulmonary segmentectomy. Nevertheless, relation of postoperative pulmonary function with intersegmental plane size was unclear, possibly suggesting compensation provided by the ipsilateral remnant lobes. Although stapler application can be limited for some intersegmental planes, its use for division of the planes in pulmonary segmentectomy for the purpose of sparing pulmonary function is acceptable for large intersegmental planes, especially in simple-type segmentectomy.

Compliance with ethical standards

Conflict of interest All authors have no conflict of interest.

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