



# Surgical Planning and the Division of the Intersegmental Plane During Thoracoscopic Segmentectomy

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## Abstract

Although lobectomy remains the gold-standard surgical treatment for non-small-cell lung cancer, the frequency of thoracoscopic segmentectomy is increasing. Multiple factors must be considered in the choice of the procedure, ranging from adequate surgical planning or simulation, tumor localization, and identification of the intersegmental plane to severing the intersegmental plane to achieve an oncologically safe surgical margin with no or minimal manual palpation and different landmarks. In this article, we present an overview of methods for each procedural step of thoracoscopic segmentectomy, from preoperative planning to division of the intersegmental plane.

## Keywords

Thoracoscopy · Segmentectomy · Lung neoplasms · Simulation

## 3.1 Introduction

Lobectomy remains the gold-standard surgical treatment for primary lung cancer [1], but the frequency of thoracoscopic sublobar resection (SLR)—especially anatomical segmentectomy, which can achieve relatively secure and sufficient surgical margins—is increasing [2]. This phenomenon might be partially explained by the following reasons. First, with the popularization of low-dose computed tomography (CT), small lung cancers, such as ground-glass opacity nodules (GGNs)—for which anatomical segmentectomy can achieve the same oncologic outcomes as lobectomy—have been detected more frequently. The characteristics of patients are also changing; physicians are more likely to encounter younger patients with small tumors for whom it is appropriate to consider a surgical extent that would spare lung parenchyma if a second cancer should develop [3]. Finally, there are increasingly many elderly patients with comorbidities in whom lung parenchyma should be preserved to reduce their postoperative morbidity and mortality [4]. In addition to primary lung cancer, segmentectomy can be performed for metastatic lung lesions or other non-malignant lung diseases, including inflammatory pseudotumors, congenital bronchial atresia, and pulmonary sequestration [5–9].

Relative to lobectomy, anatomical segmentectomy requires a thorough assessment of each patient's lung anatomy and a better understand-

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ing of the branching patterns of the pulmonary vessels and bronchi [10]. In addition, numerous variations and anomalies of the pulmonary vessels and bronchus constitute issues to be overcome before performing segmentectomy. Although thoracoscopic segmentectomy has become a more common surgical procedure, surgeons should continue to be familiar with various methods, considering multiple factors such as the surgical margin, venous drainage of the tumor, and lung anatomy to conserve.

The purpose of this article was to present an overview of methods for each step of thoracoscopic segmentectomy, from preoperative planning to division of the intersegmental plane.

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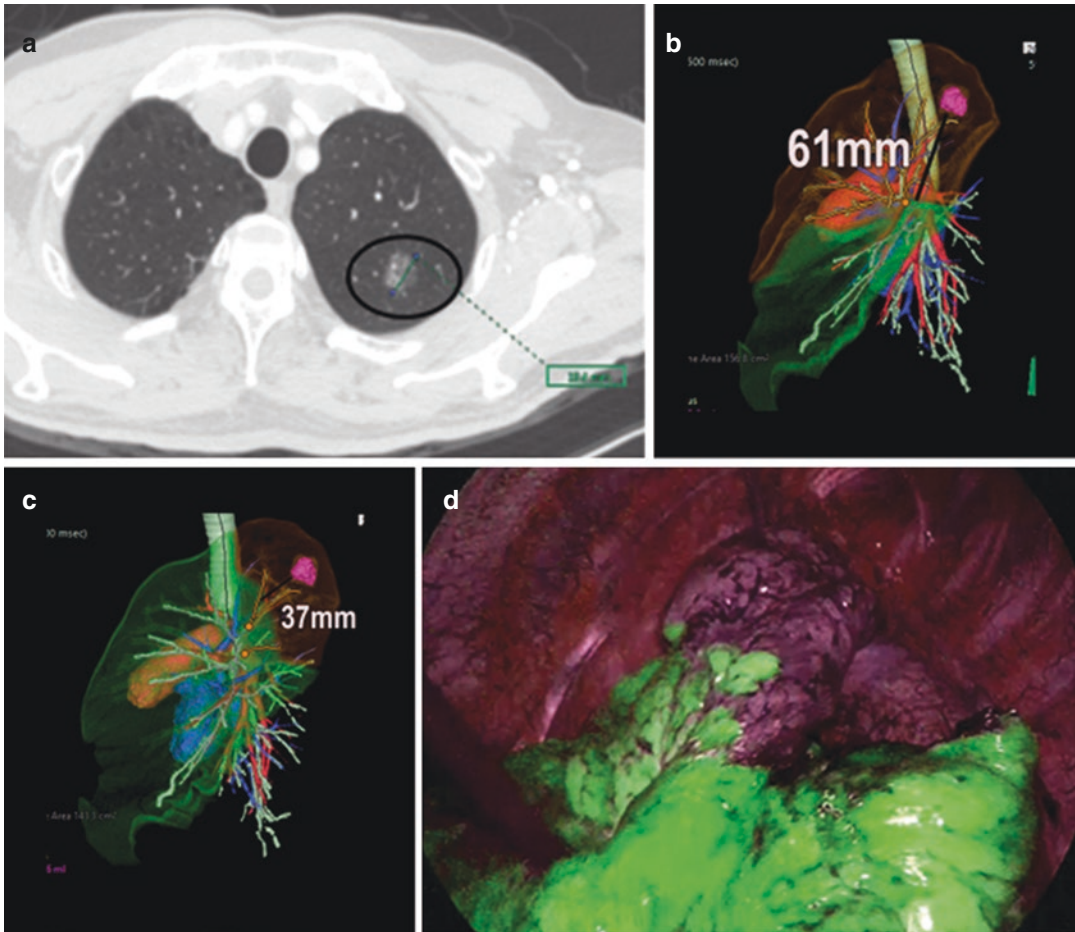
### 3.2 Preoperative Planning and Simulation

Segmentectomy is more complicated technically than lobectomy because of the anatomical complexity and variations of peripheral vessels and bronchi. Nagashima et al. [11, 12] and Shimizu et al. [13] reported that the prevalence of variations of bronchovascular patterns differed [14], sometimes significantly, from those noted by previous reports [15, 16]. In addition, unplanned procedures, such as additional wedge resection or completion lobectomy, are of concern during thoracoscopic segmentectomy [17]. Recently, three-dimensional (3D) imaging based on high-resolution CT has become more prevalent to help thoracic surgeons perform thoracoscopic segmentectomy by revealing the patient's anatomy in detail [18–22]. With this method, it is possible to: (1) specify the exact lesion location within a pulmonary segment, (2) define the segmental pulmonary artery or vein branches and bronchial tree divisions to identify possible anatomical variations, (3) calculate and integrate safety mar-

gins to prevent or decrease locoregional recurrence, (4) calculate the volume of the resected or nonresected segment, and (5) provide evidence to suggest alternative treatments in compromised patients for whom the 3D model was not suitable for anatomical segmentectomy due to anatomical or oncological reasons.

After our institution adopted a 3D workstation (SYNAPSE VINCENT: Fujifilm Medical, Tokyo, Japan) in October 2018, thin-section CT images were transferred to the 3D workstation to generate virtual 3D segmentectomy images. These simulation images were displayed on a monitor alongside the actual thoracoscopic monitor. For example, a female patient who presented with a persistent, 1.9-cm, part-solid GGN (ground-glass opacity percentage = 92%) on thin-section chest CT (Fig. 3.1a) was referred to our department and deemed suitable for SLR, with an adequate surgical margin. Although 3D reconstruction showed the safety margin (>60 mm) to be sufficient for upper-division segmentectomy, the remaining lung volume (28% of the left upper lobe [LUL] volume) was too small, suggesting insufficient preservation of the lung parenchyma (Fig. 3.1b). However, another 3D simulation (Fig. 3.1c) revealed that a safe surgical margin (37 mm) and preservation of lung parenchyma (74% of the LUL volume) could be simultaneously achieved when performing apicoposterior segmentectomy. Based on these results, apicoposterior segmentectomy was performed, and the parenchymal resection margin was measured as 3.0 cm on the pathologic examination.

However, it is important to interpret and utilize 3D models carefully in this context. Most importantly, the CT images and the consequent 3D model do not reflect lung collapse or deformity. Accordingly, the surgical margin from the 3D simulation is frequently overestimated relative to the gross or pathologic surgical margin [23].



**Fig. 3.1** (a) Axial view chest computed tomography (17-mm part-solid ground-glass nodule in the left upper lobe [LUL]). (b) A 3-dimensional (3D) simulation of left upper-division segmentectomy (virtual surgical margin: 61 mm, preserved lung volume: 392 mL [28% of the total LUL volume]). (c) A 3D simulation of left apicoposterior

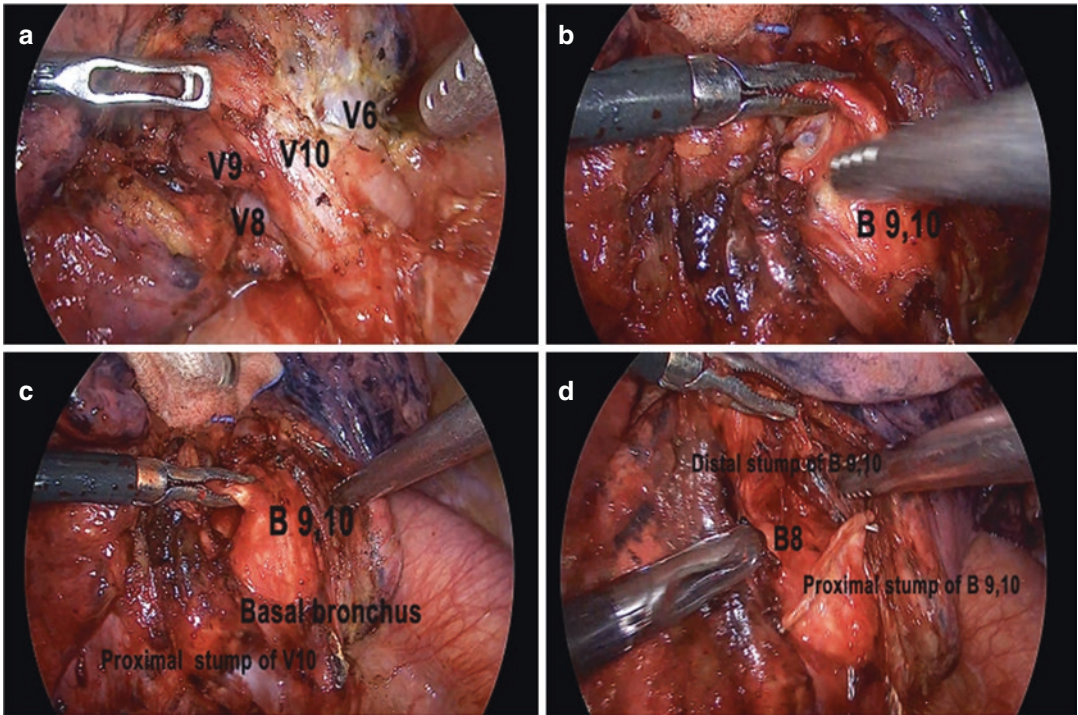
segmentectomy (virtual surgical margin: 37 mm, preserved lung volume: 1042 mL [74% of the total LUL volume]). (d) Corresponding surgical near-infrared thoracoscopy image after systemic indocyanine green injection

### 3.3 General Surgical Technique

#### Exposure of the Hilar Structures

The hilar structures should be exposed as much as possible to confirm the vascular or bronchial anatomy. For example, the left inferior pulmonary vein was dissected and exposed, as shown in Fig. 3.2a,

when performing LS9, 10 segmentectomy from the posterior side; then, the segmental bronchus was exposed and grasped with atraumatic graspers (Fig. 3.2b). The lateral and back sides of the LS9, 10 segmental bronchi were dissected and isolated from the pulmonary artery branch with scissors or a tissue dissector (Fig. 3.2c) and divided with an endlinear stapler (Fig. 3.2d).



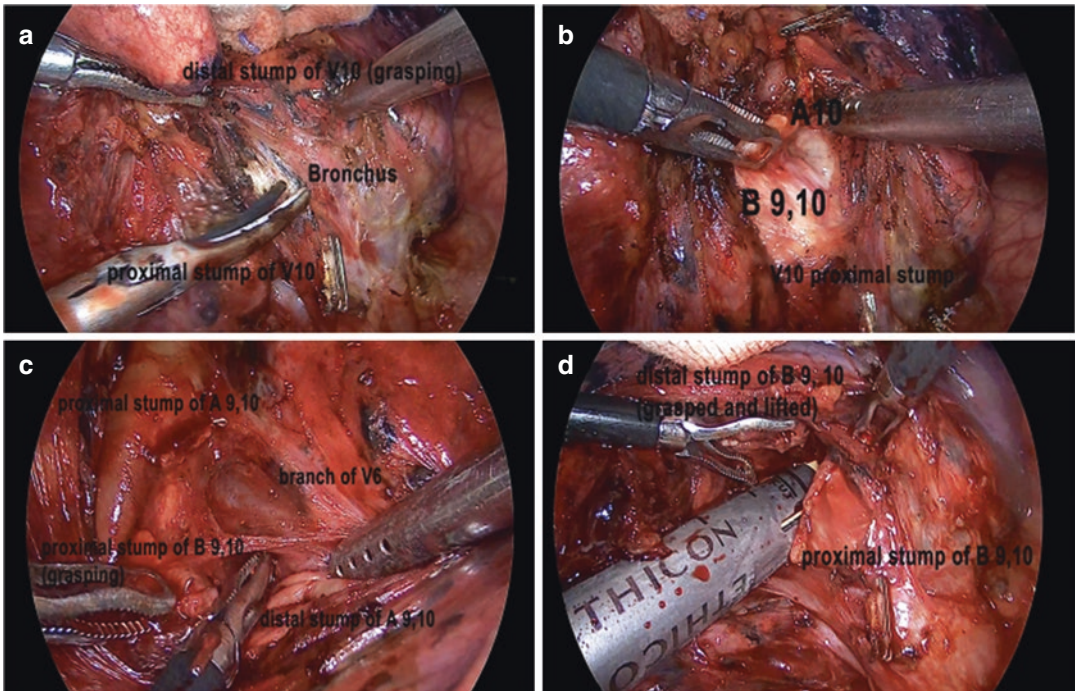
**Fig. 3.2** (a) Full exposure of the left inferior pulmonary vein from the posterior side. (b) Grasping and lifting of the segmental bronchus. (c) Dissection of the lateral and

posterior borders of the target bronchus. (d) Division and lifting of the distal stump of the target bronchus

### Lifting the Distal Stump of the Vessels or Bronchus

Grasping and lifting the distal stump of the vessels or bronchus help to expose posterior segmental hilar structures [24]. For example, Fig. 3.3a shows that lifting distal V10 enabled easy exposure of B9, 10. In addition, grasping and further

dissection of the resected bronchus help to expose and isolate the pulmonary artery branch (A10), as seen in Fig. 3.3b. Lifting the resected hilar structure also facilitates identification of the intersegmental vein branches and planes (Fig. 3.3c). Lastly, further dissection around resected hilar structures can make room for staplers (Fig. 3.3d). The technique is discussed in detail below.



**Fig. 3.3** (a) Lifting the distal stump of V10 to expose the target bronchus. (b) Grasping and lifting of B9, 10 to expose the posterior pulmonary artery. (c) Exposure of the

intersegmental vein branch after division of A9, 10 and B9, 10. (d) Stapler insertion into the hilar pocket

### 3.4 Identification of the Intersegmental Plane

It is important to recognize and mark the intersegmental plane during anatomical segmentectomy. Several techniques have been introduced and established, as discussed below and summarized in Table 3.1.

#### Inflation–Deflation Method

Before dividing the clamped bronchus, the anesthesiologist is asked to ventilate the lung; thereafter, differential deflation and inflation of the segment to be removed are expected to develop, helping to delineate the intersegmental planes [25]. Although this is the most common method, its utility is less than satisfactory because the developing line is not as clear as desired due to collateral ventilation through Cohn's pores. Tsubota [26] reported using a method involving

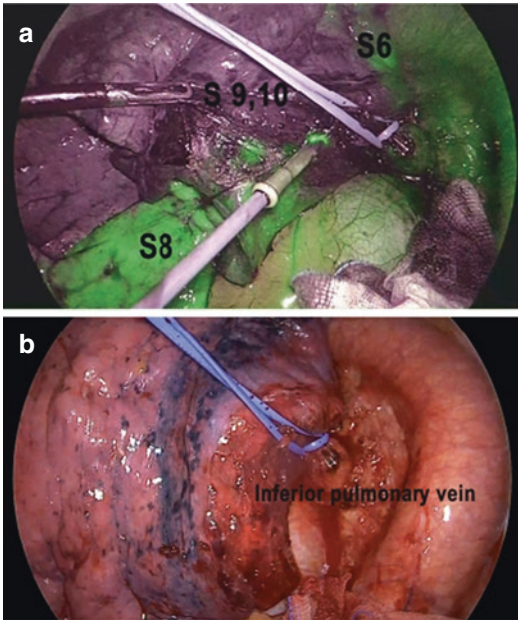
inflation of the whole lung; in this context, division of the segmental bronchus and opening of the stump of the preserved bronchus allowed the gas inside the preserved segments to escape. Okada et al. [27] suggested the utility of selective jet ventilation under flexible bronchoscopy in the segment to be resected. Other methods have been reported to inflate or keep the resected segment inflated, including bronchial ligation with a slip-knot method after inflation or direct inflation by inserting a butterfly needle into the segmental bronchus [28, 29].

#### Perfusion Method

It is often difficult to delineate the intersegmental line in patients with emphysema using the inflation–deflation method because the lung parenchyma is likely to exhibit an advanced state of collateral respiratory structures, and inflated lungs typically hamper the surgical view during thora-

**Table 3.1** Comparison of techniques to identify the intersegmental plane during thoracoscopic segmentectomy

Method	Inflation–deflation line		Virtual-assisted lung mapping
	Target segment deflated	Target segment inflated	
Advantages	<ul style="list-style-type: none"> <li>– No preparation is necessary</li> <li>– Easy and quick</li> </ul>	<ul style="list-style-type: none"> <li>– Less interference with the surgical view</li> <li>– Relatively easy</li> </ul>	<ul style="list-style-type: none"> <li>– Provides geometric information on the lung surface</li> </ul>
Disadvantages	<ul style="list-style-type: none"> <li>– Interference with the surgical view</li> <li>– Prolongation of the operation time</li> <li>– Intersegmental lines could be unclear due to collateral ventilation</li> </ul>	<ul style="list-style-type: none"> <li>– Some preparation or help of the anesthesiologist is needed</li> <li>– The needle injection method has been discarded due to air embolism</li> <li>– Intersegmental lines could be unclear due to collateral ventilation</li> </ul>	<ul style="list-style-type: none"> <li>– Requires preoperative preparation</li> <li>– Basic instruments and some facilities are needed</li> </ul>
		<ul style="list-style-type: none"> <li>– Easy and quick</li> <li>– Able to create the demarcation around the hilum</li> </ul>	<ul style="list-style-type: none"> <li>– Correct identification of the pulmonary artery is necessary</li> <li>– An emphysematous lung that is less-perfused may be misleading or confusing</li> <li>– Infrared thoracoscopy is required</li> </ul>



**Fig. 3.4** (a) Demarcation of the intersegmental plane with electrocautery after systemic indocyanine green (ICG) injection. (b) Temporary pulmonary vein clamping to prevent ICG washout

oscopic segmentectomy, often resulting in delays in the procedure. To overcome these limitations of the inflation technique, Misaki et al. [30] introduced a novel method for visualizing adjacent segments using a near-infrared camera following systemic injection of indocyanine green (ICG). In this approach, after segmental pulmonary artery ligation or division, an intravenous injection of ICG creates a fluorescent demarcation between preserved (fluorescent) and targeted (nonfluorescent) segments (Fig. 3.4a) [31, 32]. However, it is often difficult to stain and dissect the correct intersegmental line within the few minutes before the ICG dye is washed out. However, Ito et al. [33] proposed a new technique in which the pulmonary vein of the entire lobe is clamped temporarily, prolonging ICG visualization (Fig. 3.4b).

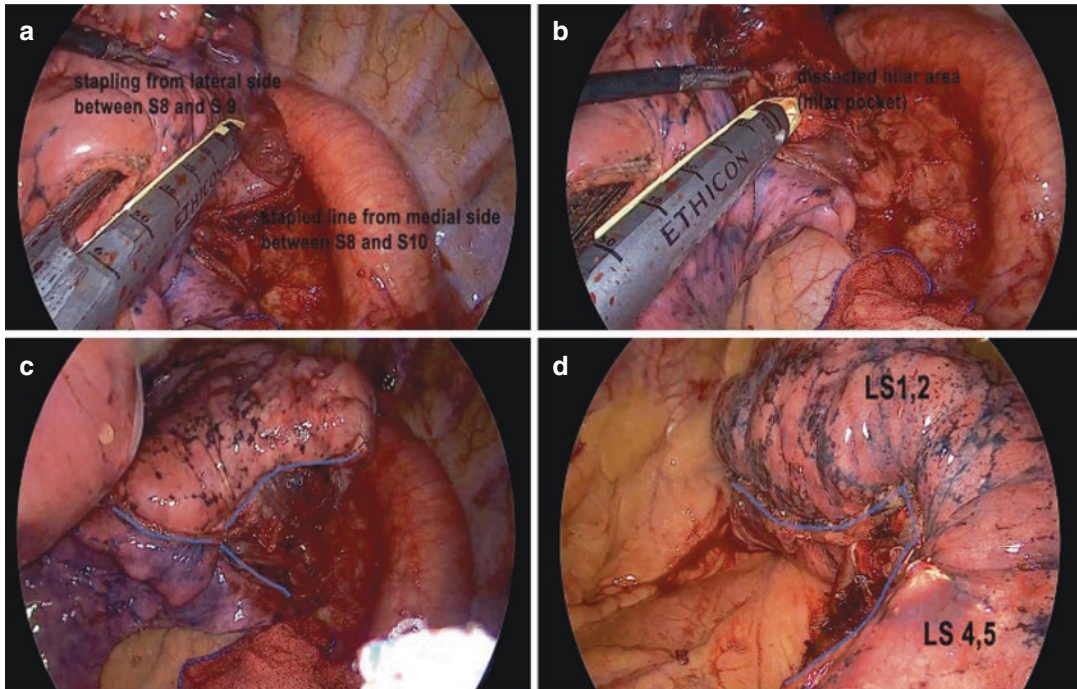
### Virtual-Assisted Pulmonary Mapping

This technique was developed as a bronchoscopic lung-marking method to avoid the inherent complications of CT-guided percutaneous lung mark-

ing. In virtual-assisted pulmonary mapping, multiple marks are made under the lung surface and provide geometric information for localizing a lesion in 3D space [34].

### Division of the Intersegmental Plane

The optimal method for dissecting the intersegmental plane remains controversial. The two main approaches to developing the intersegmental plane involve using either stapling devices or energy instruments such as electrocautery or advanced bipolar energy. The use of energy devices has been considered advantageous for preserving pulmonary function due to the avoidance of squeezing or folding of the lungs by stapler devices [27]. However, it is possible that their use may lead to more postoperative complications, such as prolonged air leakage or bronchopleural fistula [35]. Recently, a randomized controlled trial reported a higher incidence of postoperative complications (e.g., air leakage) in the electrocautery group, while no difference was found in the loss of lung function [36]. However, there remain concerns that the effect of preserving lung function would be reduced by lung-folding involving multiple stapling actions when performing thoracoscopic complex segmentectomy. There are two main principles to follow to facilitate better inflation of preserved segments after thoracoscopic segmentectomy. First, the lung should be stapled from the periphery to the hilum. If multiple intersegmental planes need to be cut, peripheral stapling at different angles should be started and continued until reaching the center or hilum (Fig. 3.5a). Second, when the stapler reaches the hilum, it should be placed in the pocket (Fig. 3.5b) created by lifting the resected hilar structures as described above to involve the hilar structures of the target segment and to avoid cutting into the preserved segments. The cartilage, rather than the anvil of a stapler, should be placed toward the hilum to minimize the risk of vascular damage. Triangular (in a Mercedes-Benz mark-like fashion) (Fig. 3.5c) or V-shaped (or U-shaped) (Fig. 3.5d) stapling can be performed using these technical principles.



**Fig. 3.5** (a) Peripheral stapling at different angles when starting the division of the intersegmental plane. (b) Placement of the stapler tip into the hilar pocket after fur-

ther dissection of the hilar area. (c) Triangular stapled line after left 9, 10 segmentectomy. (d) A U-shaped (or V-shaped) stapled line after left 3 segmentectomy

### 3.5 Conclusion

Anatomical segmentectomy with thoracoscopy involves recognizing the correct 3D anatomy of the lung segment and accurately identifying the location of the lesion preoperatively or intraoperatively. Identifying and separating the intersegmental plane correctly and safely are important steps for completing thoracoscopic segmentectomy, with some technical pitfalls. In each step, different methods might be adopted based on the physician's preferences or situation. However, a thorough understanding of the advantages and limitations of each technique can help surgeons to perform lung segmentectomy more accurately.

**Conflict of Interest** No potential conflict of interest relevant to this article was reported.

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