

**Table S1** Lung lobectomy thoracoscopic instrumentation configuration

Item	Quantity	Purpose
Curved forceps	6	Tissue separation
Sponge forceps	4	Grasping and transferring sterilized instruments
Short toothed forceps	2	Gripping harder tissues
J-hook	1	Exposing the field during thoracotomy
Dissection scissors	1	Separating, cutting, and dissecting tissues
Long needle holder	1	Cutting sutures
Suturing device	1	Performing surgical sutures
Vascular clamp	1	Occluding blood vessels
Oval forceps	2	Clamping and retracting tissues
Dissecting forceps	1	Dissecting and clamping tissues
Straight forceps	2	Tissue separation
Needle holder	3	Holding sutures for sewing various tissues
Short needle scissors	2	Cutting sutures
Curved scissors	1	Trimming tissues
Knife handle	1	Cutting tissues
Right angle forceps	1	Tissue separation
Snake head forceps	1	Tissue separation
Titanium clip/hemlock forceps	1	Clamping vascular structures under endoscopy
Vats needle holder	1	Under-the-scope suturing
Electrosurgical hook	1	Cutting tissues, hemostasis for tiny bleeding points
Thoracoscopic aspirator head	1	Aspiration, irrigation
Equipment		
Electrosurgical knife	1	Cutting and dissecting tissues
Ultrasonic scalpel	1	Cutting and dissecting tissues
Thoracoscope machine	1	

## Appendix 1 Standardization and homogenization scheme of minimally invasive precision technology for pulmonary lobectomy based on domestic innovative medical equipment

### 1. Requirements for Minimally Invasive Surgeons:

- a) Senior attending physicians (with high seniority) or above in medical authorization;
- b) Independent performance of lung resection for 3 years;
- c) Received specialized training in thoracoscopic surgery;
- d) Possess flexible adaptability and the ability to promptly switch to open chest surgery.

### 2. Indications for Pulmonary Lobe Surgery:

- a) Good lung function and absence of other severe systemic diseases, able to tolerate pulmonary lobectomy;
- b) Benign lesions requiring pulmonary lobectomy;
- c) Peripheral early-stage I-II and certain stage III lung cancer with a diameter  $\leq 7$ cm, without lymph node metastasis or limited N1 node involvement;
- d) Lesions located in the pulmonary parenchyma, unsuitable for segmentectomy.

### 3. Contraindications for Pulmonary Lobe Surgery:

- a) Preoperative evaluation suggests the possibility of multiple lymph node metastases;
- b) Central lung cancer or tumor infiltration into the bronchus;
- c) Severe dense adhesions in the thoracic cavity, including severe inflammatory lesions and pleural fusion;
- d) Unable to tolerate single-lung ventilation.

Based on the above new configuration solution, our team has established a clinical solution for minimally invasive pulmonary lobectomy, with the following specific steps:

### 1. Preoperative Assessment:

Prior to pulmonary lobectomy, lung volume measurement is conducted, and three-dimensional reconstruction technology is utilized to guide minimally invasive pulmonary lobectomy. Based on markers on the surface of the excised lung lobe, the real lung structure is simulated, and a lung cutting plan is designed, including CT image simulation of the cutting surface and auxiliary positioning, to more accurately locate the lesion, blood vessels, and bronchi based on body surface markers, reducing surgical risks. The optimized three-dimensional reconstruction model is combined with 3D printing to recreate the lung at a 1:1 scale. Subsequently, electromagnetic navigation bronchoscopy is used to locate nodules and exclude airway variations. Combined with intelligently planned surgical paths, the coordinates of important structures along the surgical path are marked, and after identifying fixed markers during surgery, the procedure is guided according to the preoperative planning for assisted positioning.

### 2. Surgical Process:

#### Anatomical Lung Lobe Resection Method:

#### a) Anesthesia, Positioning, and Incision Selection:

**Anesthesia:** General anesthesia is administered with single-lung ventilation using a double-lumen endotracheal tube.

**Positioning:** The patient is placed in a lateral decubitus position on the healthy side with the chest elevated to widen the intercostal spaces. The upper limb on the affected side is placed and fixed on a support, with the arm bent at a 90° angle from the trunk to expose the axillary region as much as possible. The operating table is adjusted to a flexed position.

**Incision:** The number of incisions required during surgery depends on the difficulty of the condition and the surgeon's preference, ranging from 1 to 3 incisions. The observation port is usually located near the 7th or 8th intercostal space and is approximately 1 cm in length. In individuals with a high body mass index, the observation port may be raised to the 6th intercostal space based on chest X-ray findings. The main operating port is located at the anterior axillary line, between the 4th and 5th ribs, extending from the anterior edge of the latissimus dorsi muscle to the chest wall, with a length of 3~5.0 cm

(adjusted according to the depth of the thoracic cavity and the position of the tumor). The selection of auxiliary operating ports may vary depending on the surgeon's preference, but typically they are located near the posterior axillary line at the 7th intercostal space, with a length of 1.5 cm, to minimize postoperative intercostal neuralgia by aligning with the observation port within the same intercostal space.

b) Surgical Sequence:

- ① Sampling of hilar and mediastinal lymph nodes is performed intraoperatively and sent for frozen section pathology.
- ② Residual tumor presence is assessed by re-sampling the bronchial stump and lung lobe margin for frozen section pathology, and if residual tumor is detected, the resection range needs to be expanded.

c) Surgical Steps of Resection:

Different lung lobes require different procedures for handling bronchi, arteries, and veins, depending on the development of the lung fissures. The boundaries of the lung lobes are determined based on the direction of the lung fissures and interlobar veins. Tissue separation is performed along these boundaries using an electric hook or ultrasonic scalpel. Linear cutting staplers are used for resection in areas where no clear anatomical landmarks are present. Subsequently, the borders of the lung lobes are determined after lung inflation under anesthesia, with pressure ventilation, low pressure, and low tidal volume to achieve lung expansion, in coordination with the anesthesiologist. Sufficient surgical margins must be ensured, and systematic lymph node dissection (N1, N2) is performed. The number of lymph nodes dissected from the mediastinum (N2) is similar to traditional lobectomy. Lymph nodes between lung lobes (N1), numbering more than 3, are sampled for frozen section pathology examination during surgery.

d) Method of Pulmonary Lobe Handling:

① Anatomical Basis of Pulmonary Lobe Resection:

- i. Each pulmonary lobe includes the lobar bronchus and its branches, along with the corresponding lung tissue;
- ii. The right lung is divided into 3 lobes, while the left lung is divided into 2 lobes;
- iii. Each pulmonary lobe has its own independent blood supply and bronchial distribution.

② Anatomical Feasibility of Pulmonary Lobe Resection:

Each pulmonary lobe constitutes a relatively independent functional unit with its own blood supply and bronchial branches. Therefore, anatomical separation and resection are feasible in surgical anatomy.

③ Sequence of Pulmonary Lobe Resection:

Dissection proceeds from the vascular hilum toward the distal end of the lung lobe. After identifying the blood supply of each pulmonary lobe, following oncological principles, the pulmonary veins are addressed first, followed by the pulmonary arteries and bronchi in sequence. Finally, the pulmonary lobes are separated along the fissures, and lung tissue is transected.

e) Steps for Right Upper Lobe Resection:

- ① The primary operative incision is placed at the level of the upper pulmonary vein or slightly lower. A thoracoscopic lung retractor is used to pull the lung laterally, usually through a posterior lateral incision;
- ② Dissection of the structures at the hilum, i.e., closure and transection, are performed using a cutting stapler through the posterior lateral incision. During closure, lung exposure is achieved by traction through the primary operative incision, and closure and transection are performed using a 2.0~2.5 mm cutting stapler;
- ③ For bronchi or interlobar fissures, a 3.54.8mm cutting stapler is used, depending on the size and thickness of the tissue. Separation of the horizontal fissure is best accomplished through the primary operative incision;
- ④ Once the pulmonary lobe is excised, it is removed through the primary operative incision and placed in a plastic or polypropylene bag.

f) Steps for Middle Lobe Resection:

- ① The primary incision is placed at the level of the middle lobe vein or slightly lower;
- ② Dissection of the structures at the hilum can be performed through a thoracoscopic cutting stapler inserted through the

posterior lateral incision or other feasible incisions, depending on different angles;

- ③ If separation of the anterior part of the main fissure is required, the ideal location for the incision with the camera is through the closure device;
- ④ Transection of the horizontal fissure is performed through the primary operative incision.

g) Right Lower Lung Resection Steps:

- ① The primary incision is placed at the level of the middle lobe vein or slightly lower;
- ② Structures at the hilum, including the inferior pulmonary vein, lower lobe bronchus, and basal pulmonary artery, can be closed and separated using a cutting stapler inserted through the primary operative incision;
- ③ Both anterior and posterior interlobar fissures can be separated through an incision with the camera placed anteriorly.

h) Left Upper Lung Resection Steps:

The incision strategy is the same as for right upper lobe lung resection. The only difference is that all structures, including the main fissure, can be separated using a cutting stapler inserted through the posterior port. A 30° thoracoscopy is particularly useful for pre-dissection and post-dissection of the bronchial branch from the posterior artery.

i) Left Lower Lung Resection Steps:

The incision strategy is the same as for right lower lobe resection. Identifying the basal artery and separating the anterior part of the main fissure helps clarify the exact relationship between the inferior pulmonary vein, lower lobe bronchial artery, and basal artery. Additionally, if the interlobar fissure is incomplete and separating the anterior part is technically difficult, an alternative approach is to anatomically isolate the inferior pulmonary vein by dissecting the bronchus, aiming for fewer interlobar fissures. On the left side, it is particularly important to clearly identify the secondary hilum to avoid separating the entire main bronchus in this situation. Once the veins and bronchi are separated, the basal artery is ligated and separated, followed by separation of the interlobar fissure.

### 3. Localization Method of Lesions:

Preoperative CT data is utilized for three-dimensional reconstruction to precisely locate nodules within the lung lobes, enabling direct resection of the target lobe during surgery.

### 4. Determination and Handling of Pulmonary Lobe Borders:

Currently, there are various methods for determining pulmonary lobe borders. Commonly used methods include the following 4: ① After cutting off the corresponding lobar bronchus, inflation is assisted by the anesthesiologist. The boundary between inflated and collapsed lung tissue is considered the lobe border; ② With intraoperative bronchoscopy assistance, ventilation is applied directly to the bronchus of the target lobe, and the boundary between inflated and collapsed lung tissue is regarded as the lobe border.

### 5. Key Points in the Surgical Procedure:

① The surgical margin should be greater than 2 cm from the edge of the tumor. If necessary, adjacent lung tissue from neighboring lobes may be resected simultaneously. ② Absorbable pads are placed on surfaces with significant tissue detachment to reduce the occurrence of tissue air leaks and bleeding. ③ The sequence of handling different pulmonary vein, artery, and bronchus varies. Vessels within the lobes are typically managed using 5 mm Hem-o-Lok clips or double-thread ligatures. Larger vessels and lobar bronchi are usually handled using linear cutting staplers.

### 6. Scope of Pulmonary Lobe Resection Lymph Node Dissection:

The dissection includes lymph nodes associated with the lobe where the tumor is located (stations 11, 12, 13), hilar lymph nodes (station 10), and mediastinal lymph nodes (left side: 4L, 5, 6, 7, 8, 9; right side: 2R, 3A, 3P, 4R, 7, 8, 9).

## **7. Postoperative Management Process:**

After surgery, all relevant clinical data of the patient are meticulously collected and subjected to standardized follow-up. Collected clinical data include significant and minor medical records, laboratory tests, imaging information, and mortality, all of which are recorded in detail whenever possible. The follow-up team conducts systematic and close postoperative follow-up.

Patient demographics, tumor location, surgery duration, blood loss, postoperative complications, number of lymph nodes removed, length of hospital stay, mortality within 30 days post-surgery, tumor size, pleural invasion, tumor staging, histological tumor type, assessment of postoperative quality of life, postoperative imaging changes, and results of blood biochemical examinations should all be rigorously documented.

For patients staged as IB postoperatively, it is recommended to consider adjuvant therapy based on the immunohistochemistry and molecular pathology results of the pathological specimens.