Clinical application of bronchial high-frequency ventilation in 2-port thoracoscopic segmentectomy

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Abstract

To evaluate the safety and clinical application of a computer-aided surgery system (CAS) combined with high-frequency bronchial ventilation in 2-port thoracoscopic anatomical segmentectomy. A total of 301 patients who underwent 2-port thoracoscopic segmentectomy between January 1, 2019 and March 1, 2022 in the 960th Hospital of the People's Liberation Army and the Department of Thoracic Surgery of Zibo Municipal Hospital were retrospectively analyzed. The experimental and control groups were created according to the different methods of appearing the intersegmental plane of the lung. The experimental group comprised 152 patients who underwent CAS reconstruction combined with high-frequency ventilation, and the control group comprised 149 patients who underwent CAS reconstruction combined with expansion collapse. The characteristics of the patients, including age, sex, smoking history, forced expiratory volume in 1 second/forced vital capacity, Maximal ventilation, diameter of pulmonary nodules, intraoperative blood loss, postoperative drainage volume, drainage tube removal time, length of hospital stay after extubation, postoperative complication rate, operation time and appearance time of the intersegmental plane, were compared between the 2 groups. All patients completed the operation between high-frequency bronchial ventilation and expansion collapse group. There was no significant difference in Forced expiratory volume in 1 second/Forced vital capacity [(101.05 ± 11.86) vs (101.86 ± 11.61)], maximum expiratory volume [(86.36 ± 17.59 L) vs (85.28 ± 17.68 L)], the diameter of lung nodules [(13.61 ± 3.51 cm) vs (13.21 ± 3.41 cm)], intraoperative blood loss [(47.50 ± 45.90 mL) vs (48.49 ± 34.65 mL)], postoperative drainage volume [(425.16 ± 221.61 mL) vs (444.70 ± 243.72 mL)], drainage tube removal time [(3.88 ± 1.85 days) vs (3.43 ± 1.81 days)], or postoperative hospital stay [(6.07 ± 2.14 days) vs (5.82 ± 1.88 days) between the experimental group and the control group ($P > .05$)]. There were significant differences in operation time [(95.05 ± 26.85 min) vs (117.85 ± 31.70 min), $P = .017$] and intersegmental plane appearance time [(2.37 ± 1.03 min) vs (14.20 ± 3.23 min), $P < .001$]. High-frequency bronchial ventilation is safe and feasible when used in quickly and accurately identifying the intersegmental plane and is worthy of clinical application in 2-port thoracoscopic segmentectomy.

Abbreviation: CAS = computer-aided surgery system.

Keywords: anatomic segmentectomy, computer-aided surgery system, high-frequency bronchial ventilation, intersegmental plane, lung cancer, 2-port thoracoscopy, VATS

1. Introduction

Lung cancer has become the second most common malignant tumor in the world, has the highest mortality rate, and accounts for 11.4% of the total cancer incidence and 18% of the total deaths.[1] With the widespread application of thin-slice CT, the detection rate of small pulmonary nodules has significantly increased.[2] Despite some nodules only requiring regular follow-up, some nodules require surgical treatment.[3] For early-stage lung cancer nodules that are <2 cm in size, thoracoscopic anatomic segmentectomy can achieve the same therapeutic effect as a lobectomy while preserving more lung function.[4–6] The most important factor in anatomical segmentectomy is to accurately define and properly handle the plane of the lung segment[7] to ensure a safe surgical margin.[8] The commonly used methods to determine the intersegmental plane are the indocyanine green fluorescence staining method[9] and the inflation collapse method.[10] There are very few reports on using bronchial high-frequency ventilation to determine the intersegmental plane. This study analyzed the safety and clinical application value of a computer-assisted surgery system combined with bronchial high-frequency ventilation in 2-port thoracoscopic anatomical segmentectomy.

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2. Materials and methods

2.1. Clinical data

A total of 301 patients who underwent a 2-port thoracoscopic anatomic segmentectomy between January 1, 2019 and to March 1, 2022 were selected from the 960th Hospital of the People's Liberation Army and the Department of Thoracic Surgery of Zibo Municipal Hospital. The inclusion criteria were as follows: patients who had nodules with a diameter of ≤20 mm, as indicated by chest CT examination, and with ground-glass opacity and a solid component of <50% on CT, which are characteristics that are in line with the 2017 National Comprehensive Cancer Network non-small-cell lung cancer guidelines for the segmentectomy Surgical criteria; patients with normal cardiopulmonary function; patients in whom other systemic malignant diseases were excluded; patients who had partial MRI, upper abdominal color Doppler ultrasound or CT, ECT bone scan or PET/CT, etc, to exclude the presence of distant metastasis; and patients who underwent preoperative examinations, including routine blood, urine, liver and kidney function, coagulation function, blood type, pulmonary function, and electrocardiogram examinations, that showed no contraindications to surgery. The exclusion criteria were as follows: patients with pulmonary nodules with a diameter of more than 20 mm; patients with pulmonary nodules with a diameter of less than 20 mm, a ground-glass opacity, and a solid component of more than 50% on CT; patients who had rapid intraoperative pathological confirmation of a solid cancer or patients with micropapillary carcinoma who needed a radical operation for lung cancer; patients with severe complications of other organs and who could not tolerate examinations or surgery; patients with neurological or mental diseases and who could not cooperate with the examination; and patients with missing clinical data.

2.2. Research methods

Preoperative preparation: All patients underwent chest CT plain scans (Fig. 1) and enhanced scans before surgery. The CT images were imported into a computer-aided surgery system (CAS), and 3D reconstruction was performed by extracting and segmenting the pulmonary vascular and bronchial regions. The pulmonary nodules were extracted by volume calculation and by using a virtual simulation of the thoracic and lung resection (Fig. 2) to visualize the resection surface and the extent of the surgical margins. The patients were evaluated preoperatively. The margin of segmentectomy and the accurate positioning of the pulmonary nodules were determin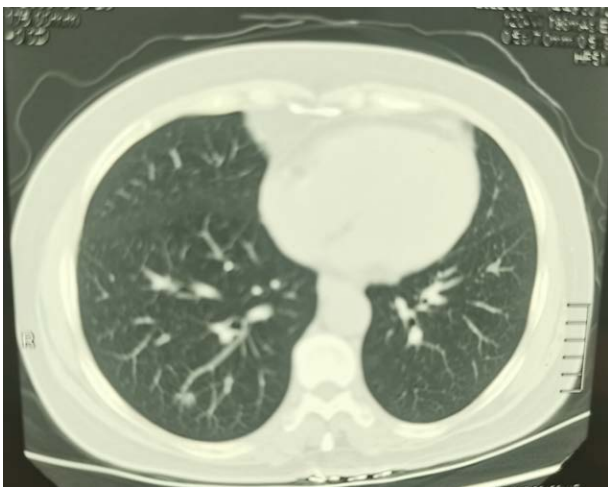ed, a clear surgical route was determined through the 3D reconstruction model, and the position of the nodules were determined according to the surgical assistance system. Any unnecessary operations and surgical risks were reduced.

Operative technique: the patients were placed under general anesthesia with double lumen tracheal intubation and ventilation of the contralateral lung. The patients were placed in the lateral decubitus position and the jackknife position, and 2 incisions were made (the 7th–8th intercostal space in the midaxillary line was the thoracoscopic observation hole, and the 3rd to 5th intercostal space between the midclavicular line in the anterior axillary line was the operation hole). According to the preoperative pulmonary nodule location, the target lung segmental bronchus was located by the fiber bronchus, and oxygen was injected into the target lung segment with a high-frequency jet ventilator. The expansion and collapse method was performed in the control group. An electric hook was used to quickly mark the intersegmental plane, the target segment artery and bronchus were dissected out according to the preoperative simulation route, the target segment blood vessel and bronchus were cut off, the intersegmental plane was cut with a linear cutting closure, and the target segment was removed (Fig. 3).

2.3. Statistical analysis

Statistical analysis was performed using SPSS 25.0 software. The measurement data that conformed to the normal distribution were expressed as the mean ± standard deviation $(\bar{x} \pm s)$. Categorical or enumeration data were expressed as the frequency and percentage, and $P < .05$ was considered statistically significant. This study has been approved by the Ethics Committee of Zibo Municipal Hospital.

3. Results

The general clinical data of the patients were collected. The age of the experimental group was 56.67 (±11.66) years old, and that of the control group was 57.56 (±12.69) years old. Eighteen patients in the experimental group had a smoking history compared to 21 patients in the control group. There were 64 males (42.11%) and 88 females (57.89%) in the experimental group, and 70 males (46.98%) and 79 females (53.02%) in the control group. There was no significant difference in Forced expiratory volume in 1 second/forced vital capacity [(101.05 ± 11.86) vs (101.86 ± 11.61)], maximum expiratory volume [(86.36 ± 17.59 L) vs (85.28 ± 17.68 L)], diameter of lung nodules [(13.61 ± 3.51 cm) vs (13.21 ± 3.41 cm)], intraoperative blood loss [(47.50 ± 45.90 mL) vs (48.49 ± 34.65 mL)], postoperative drainage [(425.16 ± 221.61 mL) vs (444.70 ± 243.72 mL)], drainage tube removal time [(3.88 ± 1.85 days) vs (3.43 ± 1.81 days)], or length of postoperative hospital stay [(6.07 ± 2.14 days) vs (5.82 ± 1.88 days)] between the 2 groups ($P > .05$). There were significant differences in operation time [(95.05 ± 26.85 min) vs (117.85 ± 31.70 min), $P = .017$] and intersegmental plane appearance time [(2.37 ± 1.03 min) vs (14.20 ± 3.23 min), $P < .001$] (Table 1).

Because the operation was successful in all the patients, conversion to thoracotomy or second operation was not needed for any of the patients. Although none of the patients in the experimental group died during hospitalization, 1 patient in the control group died of heart failure. In the experimental group, the intersegmental plane was clearly displayed, however, the intersegmental plane could not be completely labeled in 5 patients (3.29%), and no nodules were observed in 4 patients (2.63%). In the control group, the intersegmental plane could not be clearly displayed in 8 patients. Postoperative complications occurred in 7 patients (4.60%) in the experimental group, including 2 cases of pulmonary infection, 1 case of atelectasis, 1 case of atrial fibrillation, 2 cases of hemoptysis and 1 case of air leakage. In the control group, 9 patients (6.04%)
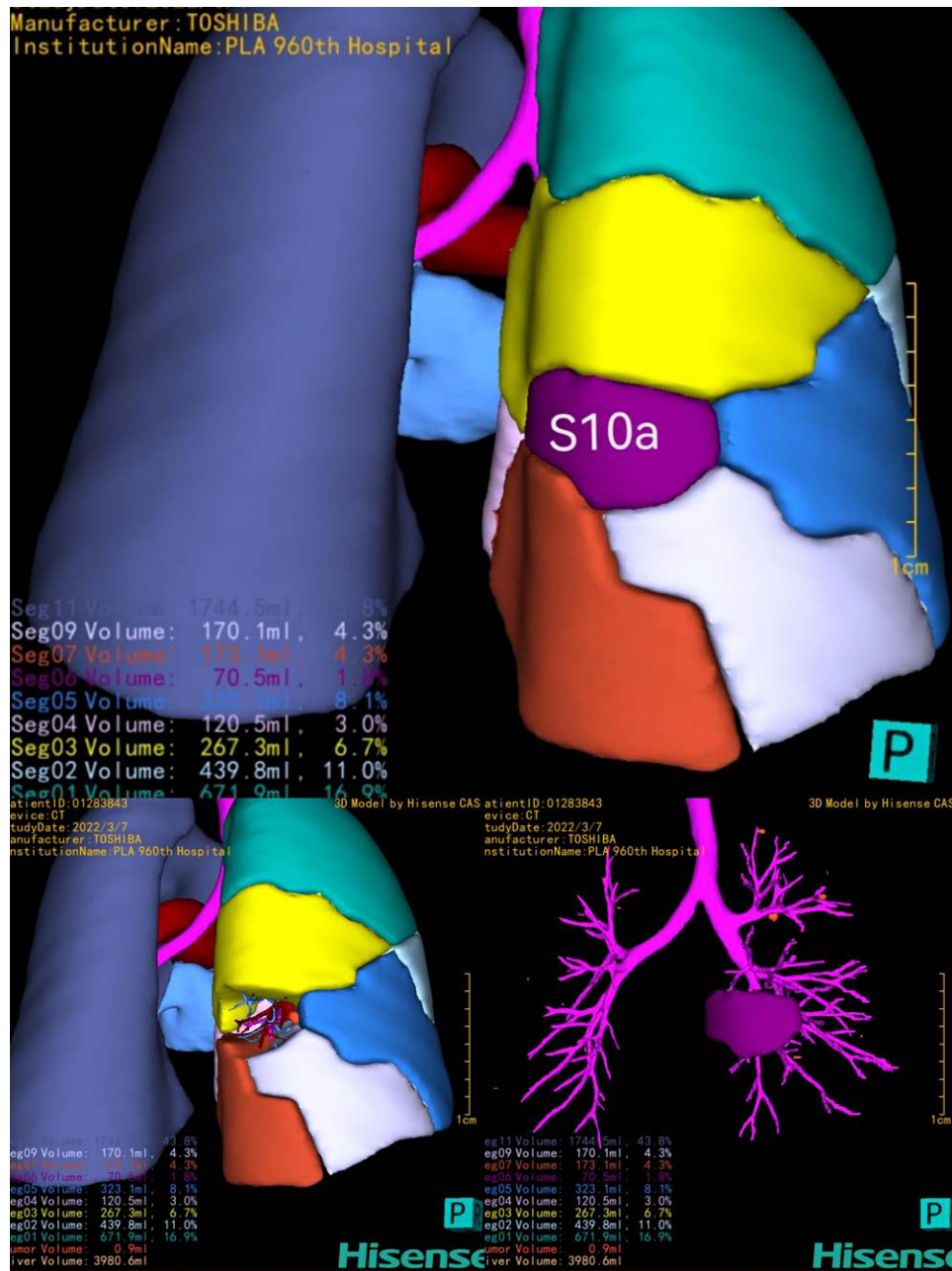

Figure 1. Localization of the pulmonary nodules on chest CT scans.

Figure 2. The computer-assisted surgery system simulates the location of the nodule.

developed postoperative complications, including 2 cases of pulmonary infection, 2 cases of hemoptysis, 1 case of arrhythmia and 4 cases of air leakage. All the patients underwent symptomatic treatment, including controlling infection with drugs, controlling arrhythmia and extending the time of drainage tube placement, recovered and were discharged from the hospital. The pathological results of the experimental group showed benign lesions in 8 patients (5.26%), atypical adenoid hyperplasia in 55 patients (36.18%), carcinoma in situ in 46 patients (30.26%), microinvasive adenocarcinoma in 29 patients (19.08%) and invasive adenocarcinoma in 14 patients (9.21%). In the control group, the postoperative pathological results showed benign lesions in 11 patients (7.38%), atypical adenoid hyperplasia in 48 patients (32.21%), carcinoma in situ in 53 patients (35.57%), microinvasive adenocarcinoma in 28 patients (18.79%) and invasive adenocarcinoma in 9 patients (6.04%) (Table 2). The pulmonary nodules were located in the lung segments (Table 3).

4. Discussion

Ground glass nodules appear in the lung in the early stage of lung cancer, and the 5-year survival rate after operation is approximately 100%.[11] Considering the popularity of 3-port video-assisted thoracoscopic surgery, single-port video-assisted thoracoscopic segmentectomy has obvious advantages.[12] Compared with 3-port thoracoscopic technology, 2-port video-assisted thoracoscopic technology does not require an incision, thus reducing the risk of intercostal nerve injury and the incidence of postoperative pain, and significantly shortening the time of chest closure.[13] The visual field of the 2-hole thoracoscope is the same as that of the 3-hole thoracoscope. For upper mediastinal lesions, single-port or 2-port thoracoscopy has obvious advantages.[14] The shortcoming of this study is that the data of the 3-port thoracoscopic technique and that of the 2-port thoracoscopic technique have not been statistically analyzed. In 2009, Akiba[15] further proposed that 3D reconstruction
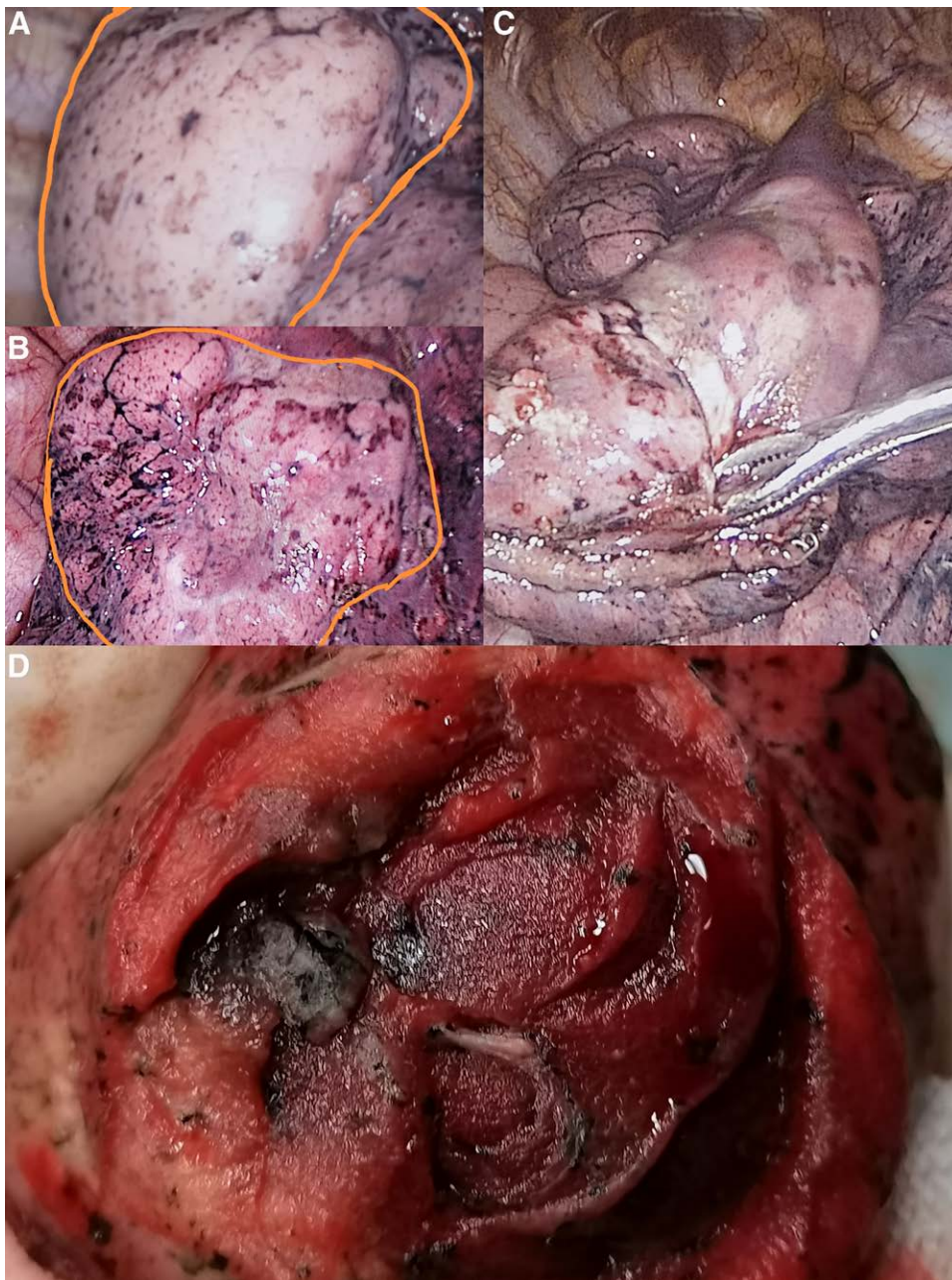
Figure 3. Images during high-frequency ventilation of the bronchus (A), Image after bronchial high-frequency ventilation (B), Image after S10a segmentectomy (C), The precise location of the nodule in the lung segment (D).

technology can be applied to pulmonary arteries, pulmonary veins, bronchi and tumors. In the preoperative period, Chen-Yoshikawa[16] performed a 3D-CT reconstruction for thoracic surgery and restored 3D geometric figures, which provided a basis for the development of individualized surgical plans in the clinical setting.[17] The computer aided surgical system used in this study is a combination of 3D reconstruction technology and a computer intelligence system.

The basic clinical data of the patients were collected in this study. The proportion of patients with a smoking history in the 2 groups was 11.84% and 14.09%, respectively. There was no significant difference in preoperative measurement indexes such as forced expiratory volume in 1 second/forced vital capacity, maximum expiratory volume, or diameter of lung nodules. There was no significant difference in intraoperative blood loss, postoperative drainage volume, drainage tube removal time or postoperative hospital stay between the

experimental group and the control group. Preoperative and postoperative indexes had little influence on the above factors. The lung segment between plane and the operation time had a significant effect on the 2 indicators. There was no significant anatomical boundaries between lung segment, segment between the plane of confirmation is one of the difficult points of thoracoscope anatomical sex lung resection surgery.[18] At present, the commonly used methods of confirming the section between the surface are indocyanine green fluorescent staining,[9,19] inflation-collapse method[10] and bronchial ventilation method.[20] The research in this study is based on the bronchial ventilation method and the expansion collapse method. At present, the expansion collapse method is the commonly performed clinical method and is divided into the traditional inflation method and the modified expansive method. Because of the Kohn hole, it is necessary to first excise the lung segment and then inflate the adjacent lung; however, at this point it is

Table 1

Basic clinical data of the patients [cases (%)/x̄±s].

Clinical information	Experimental group	Control group	t/x2	P value
Age	56.67 ± 11.66	57.56 ± 12.69	−0.636	.159
Sex			0.361	.247
Male	64 (42.11%)	70 (46.98%)		
Female	88 (57.89%)	79 (53.02%)		
Smoking history	18 (11.84%)	21 (14.09%)	0.157	.394
Nodule diameter (mm)	13.61 ± 3.51	13.21 ± 3.41	0.979	.636
Maximum ventilation (L)	86.36 ± 17.59	85.28 ± 17.68	0.535	.939
Forced expiratory volume in 1 s/forced vital capacity (%)	101.05 ± 11.86	101.86 ± 11.61	−0.601	.598
Intersegment plane appearance time (min)	2.37 ± 1.03	14.20 ± 3.23	−43.004	<.001
Successful positioning (case)	147 (96.71%)	141(94.63%)	0.652	.748
Intraoperative blood loss (mL)	47.50 ± 45.90	48.49 ± 34.65	0.211	.116
Operation time (min)	97.50 ± 31.67	117.85 ± 31.70	−6.443	.017
Postoperative drainage	425.16 ± 221.61	444.70 ± 243.72	−0.728	.482
Extubation time (days)	3.88 ± 1.85	3.43 ± 1.81	2.142	.854
Postoperative complications (cases)	7 (4.61%)	9 (6.04%)	1.457	.731
Length of postoperative hospital stay (d)	6.07 ± 2.14	5.82 ± 1.88	1.092	.211

Table 2

Postoperative pathological findings.

Postoperative pathological	Experimental group (n = 152)	Control group (n = 149)
Benign lesion	8 (5.26%)	11 (7.38%)
Atypical adenoid hyperplasia	55 (36.18%)	48 (32.21%)
Carcinoma in situ	46 (30.26%)	53 (35.57%)
Minimally invasive adenocarcinoma	29 (19.08%)	28 (18.79%)
Invasive adenocarcinoma	14 (9.21%)	9 (6.04%)

Table 3

Distribution of pulmonary nodules in experimental group and control group.

Pulmonary segment	Experimental group (n = 152)	Control group (n = 149)
LS1 + S2	19 (12.50%)	21 (14.09%)
LS3	11 (7.24%)	12 (8.05%)
LS6	15 (9.87%)	7 (4.70%)
LS9	16 (10.53%)	13 (8.72%)
LS10	12 (7.89%)	11 (7.38%)
RS1	14 (9.21%)	6 (4.03%)
RS2	6 (3.95%)	10 (6.71%)
RS1 + 2	5 (3.29%)	8 (5.37%)
RS3	18 (11.84%)	14 (9.40%)
RS6	10 (6.58%)	11 (7.38%)
RS9	7 (4.61%)	21 (14.09%)
RS10	8 (5.26%)	15 (10.07%)

difficult to accurately determine the section plane. At present, the modified inflation-collapse method is the most widely performed method. After the bronchi of the preresected lung segment is accurately assessed and treated, the lungs are inflated by positive pressure ventilation using a high frequency and a low volume through endotracheal intubation. The lung ventilation of the contralateral side is restored after the lobe in the preresected lung segment is completely expanded, and the intersegmental plane is clearly displayed. The modified inflation-collapse method can determine the planes between 2 or more pulmonary segments at a time. This method has certain limitations. First, the anesthesiologist is required to accurately complete one-lung ventilation and reinflate the affected lung after cutting off the target blood vessels and trachea, resulting in limited thoracic operation space, poor lung function, and chronic obstructive pulmonary disease. In patients with extensive pleural adhesions, it is difficult to collapse the lung and to identify the intersegmental plane. The time for the appearance of the intersegment plane in the inflation-collapse method is substantially prolonged. Indocyanine green can react with plasma protein and lipoproteins, form the nanoparticles,[21] and in 750 ~ 810 nm infrared light source, its fluorescence characteristics can be excited.[22] After the rapid injection of indocyanine green through a peripheral vein and by switching to the fluorescence mode, the reserved area, but not the target segment, emits fluorescence due to the presence of indocyanine green, and a color difference boundary is formed between the 2, thereby showing the intersegment plane.[23] In this method, the surgeon does not need to consider the real-time status of the lung tissue, the injection into a peripheral vein is relatively safe and simple, and the operation time is shortened. However, indocyanine green can bind to almost all proteins,[24] which may increase nonspecific fluorescence, and there is a drawback of false positive fluorescence imaging. Therefore, near-infrared thoracoscopy must be used during surgery, the equipment is expensive, and there is a higher cost to the patient. Therefore, it is not suitable for patients who are allergic to imaging agents, the fluorescence duration is approximately 110 s, and the diffusion takes longer. The bronchoscopy high-frequency ventilation method uses a fiberoptic bronchoscope to locate the target lung segment bronchus and a high-frequency jet ventilator to inject oxygen into the target lung segment. During the process of jet ventilation, the pressure and frequency must be controlled. Rapid expansion and collapse of the remaining normal tissue causes marking of the intersegmental plane. This method is fast and simple and is not affected by the communicating arteries between the lung segments. It is suitable for the confirmation of the subsegmental plane, greatly shortens the anesthesia time, reduces the anesthesia reaction and operation time and is in line with the concept of rapid rehabilitation therapy. To improve the accuracy of the targeted lung segment, this study improved the traditional technology and adopted the method of intraoperative bronchial light recognition to enter the targeted lung segment and to turn on the front light of the fiberoptic bronchoscope, which is consistent with the target segment shown under the thoracoscope, to again ensure the accuracy of the target segment. The disadvantage of this method is that it requires the anesthesiologist to locate each lung segment accurately and anatomically, and the surgeon must quickly and skillfully mark the intersegmental plane. In this study, the intersegmental plane marking was not completed in 5 of the patients due to the

poor surgical proficiency of the surgeon, but the postoperative complications were not significantly different from the other methods.

Through the collection and analysis of the clinical data of 152 patients, the high-frequency bronchial ventilation method can quickly, accurately and clearly display the segment plane, reduce the difficulty of the operation, shorten the operation time, and provide a reliable technical guarantee for thoracoscopic anatomical segmentectomy. It is a safe and effective method worthy of clinical application.

There are still some deficiencies in this study. The sample size is small, it is only a retrospective study of 2 centers, and the long-term prognostic effect still needs further clinical observation.

Author contributions

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Writing – original draft: Bing Li.
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