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Three-dimensional imaging assisted segmentectomy in the treatment of localized bronchiectasis: a retrospective analysis

Zhiwei Yan[1], Jian Feng[1,2], Xinyu Zhu[1], Ziqing Shen[1], Jun Zhao[1] and Jinfeng Ge[1*]

Abstract

Background Surgical treatment is crucial in managing bronchiectasis. Segmentectomy, although a complex procedure, has become more feasible with advancements in thin-slice CT and three-dimensional imaging. These technologies enhance preoperative anatomical understanding and surgical planning. This study aims to demonstrate the viability of using three-dimensional imaging assistance for treating localized bronchiectasis through segmentectomy.

Methods From 2021 to 2023, a total of 34 patients with bronchiectasis underwent segmentectomy. We collected and then analyzed potential factors including general conditions, preoperative clinical symptoms, surgical procedures, length of postoperative hospital stay, incidence of postoperative complications and postoperative follow-ups.

Results Of the 34 surgical patients, 8 were men and 26 were women, resulting in a total of 34 operations. The average surgical time for segmentectomy was 157.7 ± 63.4 min. The average intraoperative blood loss was 115.9 ± 107.4 ml. Postoperative tube placement lasted an average of 6.5 ± 2.4 days, with an average drainage volume of 724.7 ± 500.9 ml. The average hospital stay was 8.2 ± 3.4 days. Among these patients, 2 developed pneumothorax and 2 experienced air leaks. Additionally, 4 patients developed pneumonia postoperatively. Over an average follow-up period of 14.3 months, most patients showed symptom improvement, with only two cases of recurrence.

Conclusions Segmentectomy has acceptable postoperative morbidity, mortality, and outcomes. Therefore, segmentectomy is a viable option for the treatment of localized bronchiectasis.

Keywords Bronchiectasis, Segmentectomy, Three-dimensional imaging, Outcomes

Zhiwei Yan and Jian Feng are co-first authors.

*Correspondence:
Jinfeng Ge
gejinfeng2021@163.com
[1]Department of Thoracic Surgery, The First Affiliated Hospital of Soochow University, Suzhou 215006, China
[2]Department of Thoracic Surgery, Funing People's Hospital, No. 129 Fucheng Street Road, Funing County, Yancheng City, Jiangsu Province 224400, China

Introduction

According to a clinical review on bronchiectasis published in the New England Journal of Medicine in 2022, bronchiectasis is a complex condition associated with various factors, including lower respiratory infections, tuberculosis, and immune system deficiencies. The prevalence of the disease in China's general population is higher among women than men and increases with age. Physicians diagnose bronchiectasis in 1.5% of women and 1.1% of men [1]. The destruction of normal elastic tissue and cartilage in the bronchial wall leads to fibrosis, resulting in loss of elasticity and contraction of surrounding tissue [2–4]. This, ultimately, causes dilation of affected bronchi characterized by chronic cough, copious production of purulent sputum, and recurrent hemoptysis [5].

For patients with localized lesions who have failed drug therapy or cannot tolerate drug therapy, recurrent hemoptysis or both, surgical treatment is usually taken [6, 7]. Segmentectomy has been gradually promoted in recent 20 years, and its application in thoracic surgery has become more and more extensive. Compared with lobectomy, the advantages of segmentectomy are the preservation of lung function, low incidence of surgical complications and mortality, less intraoperative blood loss, and shorter hospital stay, etc [8, 9].

Due to the indistinct demarcation between lung segments, surgical separation of these segments poses a challenge, potentially leading to inadvertent damage to adjacent lung tissue. Proficient surgical skills are imperative for successful lung segment resection. Segmentectomy of the lung has higher requirements for doctors. Nevertheless, advancements in thin-slice CT and three-dimensional imaging have enabled preoperative anatomical comprehension and surgical planning. This study aims to demonstrate the viability of employing three-dimensional imaging assistance for localized bronchiectasis treatment through segmentectomy.

Materials and methods

Patient screening

This study collected and reviewed the data of patients with bronchiectasis treated Department of Thoracic Surgery at the First Affiliated Hospital of Soochow University from the past three years. The data collection process involved screening all patients who had undergone surgery for bronchiectasis. First, patients with non-localized bronchiectasis were excluded. Second, patients who could not tolerate extensive resection and opted for palliative resection were also excluded.

The inclusion criteria for patients are as follows: (1)The HRCT scan must show that the lesion is well-defined and confined to one or several segments within a single lung lobe. (2)The patient must present with chronic cough, sputum expectoration, multiple episodes of pulmonary infection, or recurrent or significant hemoptysis, and standard medical treatment must be ineffective. (3) A preoperative systematic evaluation must confirm that the patient can tolerate surgery. Non-response to conservative treatment was defined as frequent exacerbations that significantly impacted normal occupational or social functioning or necessitated multiple hospitalizations. Non-surgical interventions encompass antibiotic therapy, physical therapy, bronchodilators, and corticosteroid treatment.

Preoperative assessment

Prior to the surgical procedure, each patient undergoes a comprehensive medical history review, physical examination, pulmonary function assessment, vascular ultrasound, and laboratory tests (including blood cell analysis, sputum culture, arterial blood gas analysis). Smokers are required to abstain from smoking for a minimum of two weeks before surgery. Lastly, the patient's cardiopulmonary function is systematically evaluated by both the surgeon and anesthesiologist.

High-resolution imaging has transformed the diagnosis and monitoring of bronchiectasis, establishing itself as the gold standard for disease identification and localization [10]. Even with a 10 mm slice thickness in HRCT, it is adequate for determining the distribution and severity of the disease, exhibiting a sensitivity of 66% and a specificity of 92% [11]. Based on the HRCT examination results, disease progression and the most severe areas are identified to safeguard healthy lung tissue. The resulting medical digital imaging and communication (DICOM) files are then uploaded to three-dimensional imaging software (InferVision) in order to generate a 3D virtual model of the lung, airways, and vascular system (Figs. 1 and 2). Subsequently, based on the three-dimensional imaging findings, the surgeon gains comprehensive insight into the patient's lung anatomy prior to surgery and can accordingly plan surgical procedures.

Surgical techniques

All of patients underwent single port thoracoscopic surgery.The technical difficulties in segmenting pulmonary lobar vessels and bronchi may be the main limiting factor in the success of the surgery. All patients were under general anesthesia, and the anesthesiologist used a double-lumen tube to intubate the trachea through the mouth, providing independent ventilation for each lung to prevent secretions from flowing to the other side and reducing contamination of the lungs during the operation. Prior to segmentectomy, it is essential to meticulously identify the arterial supply to the affected lobe of the lung. Subsequently, precise dissection of the segmental artery should be performed

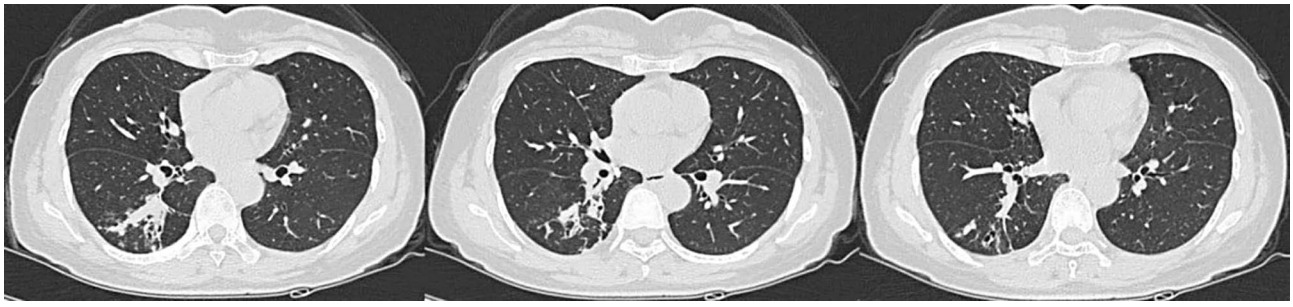

Fig. 1 A 55-year-old female patient with bronchiectasis lesions on CT, affecting the superior segment of the right lower lung

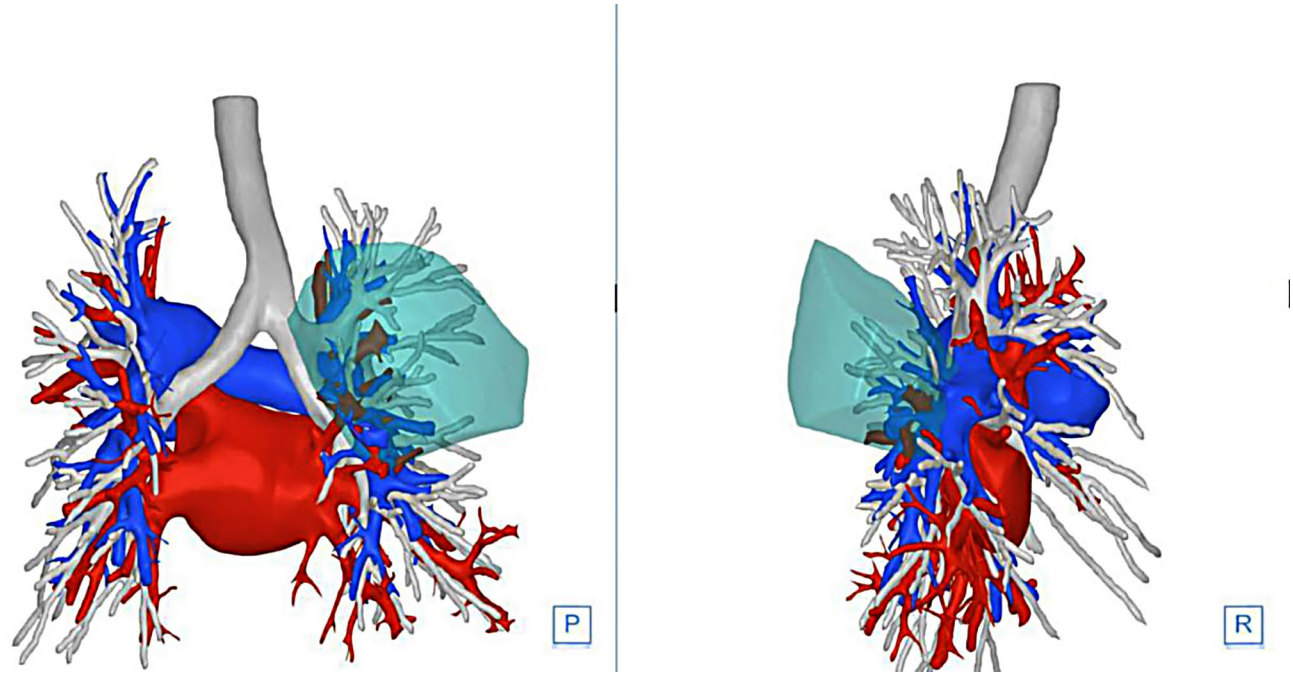

Fig. 2 A three-dimensional imaging of the lungs obtained from the CT results of Fig. 1. The shaded area represents the right lower lobe superior segment and bronchiectasis lesion

based on this identification. Identification and isolation of the segmental vein should follow, with subsequent ligation and transection. The segmental bronchus must then be identified and transected. Following inflation of the lung, careful observation for a distinct demarcation between the affected and healthy segments is imperative. Bronchiectasis, being a chronic disease, is often accompanied by emphysema in some patients, which can render the inflation-retraction method unsuitable for them. To address this issue, we employed indocyanine green as a fluorescent agent, injecting it into the patient's body to enhance visualization. Utilizing a fluorescent thoracoscope, we were able to clearly delineate the boundaries between lung segments. Subsequently, we marked these boundary lines using high-frequency electrosurgical equipment. Finally, an endoscopic cutter stapler was employed to perform the cutting procedure. Any observed air leakage can be addressed through suturing with fine suture material. Pathological examination should be conducted on all resected specimens to confirm diagnosis.

Postoperative management

The probability and mortality rate of postoperative complications are not only related to the operation, but postoperative care is equally important as well [12]. Postoperative care involves rigorous physical therapy, administration of antibiotics, and analgesics.It is noteworthy that the majority of bronchiectasis patients are elderly, with a high prevalence of cardiovascular diseases and other comorbidities, necessitating similar attention to post-surgical management of these conditions. All patients are administered routine antibiotics for five days following surgery. In the event of a postoperative infection, treatment is tailored based on sputum culture results and antibiotic sensitivity

Table 1 Patient characteristics

Demographic	Segmentectomy group (*n* = 34)
Age, range (years)	26–76 (mean:55.1)
Sex	
Male	8 (23.5)
Female	26 (76.5)
Smoke, n (%)	6 (17.6)
COPD, n (%)	3 (8.8)
FEV1% predicted, (mean ± SD)	83.4 ± 17.8
Surgical indications, n (%)	
Failure of drug therapy	10 (29.4)
Treating hemoptysis	24 (70.6)
Symptom, n (%)	
Cough	28(82.4)
Sputum	28(82.4)
Hemoptysis	20 (58.8)
Chest pain	2 (5.9)
The location of the lesion, n (%)	
Left upper lobe	10 (29.4)
Left lower lobe	18 (52.9)
Right upper lobe	6 (17.6)
Right middle lobe	0
Right lower lobe	6 (17.6)

COPD, chronic obstructive pulmonary disease. FEV1, Forced expiratory volume in 1 s

tests, with the potential use of combination therapy if necessary. Some patients receive tramadol as a pain relief treatment. The chest X-ray is performed at the bedside on the first postoperative day to assess lung re-expansion, while blood routine and electrolyte levels are assessed on the second day for any abnormal findings. The nurse records the color and amount of the pleural fluid, as well as the color, amount, and consistency of sputum daily. The patient is encouraged to cough and expectorate after surgery to promote lung reexpansion and prevent the accumulation of sputum in the lungs, which can lead to infection. Furthermore, bronchoscopic examinations were conducted on patients presenting with mucus impaction and atelectasis. Reiterate the importance of encouraging the patient to mobilize in order to facilitate pleural fluid drainage, mitigate the risk of thrombosis, and expedite wound healing. After surgery, patients who develop lung air leaks may be related to excessive pleural adhesion or over-resection of lung tissue. We effectively addressed the issue of lung air leaks using a negative pressure suction method, obviating the need for further surgical intervention. When the daily drainage volume is less than 150 ml, the effluent appears clear with no evidence of air leak. Subsequent chest X-ray should be conducted to verify lung re-expansion, and consideration may be given to chest tube removal. A follow-up outpatient clinic visit for chest X-ray examination one week post-discharge is recommended to monitor lung expansion and fluid accumulation. If an increase in fluid accumulation is observed during follow-up, a chest puncture or closed chest drainage procedure may be considered for the patient.

Table 2 Surgical procedures and follow-up

Factor	Segmentectomy group (*n* = 34)
Duration of the surgery, min, (mean ± SD)	157.7 ± 63.4
Intraoperative blood loss, mL, (mean ± SD)	115.9 ± 107.4
The duration of chest tube placement, day, (mean ± SD)	6.5 ± 2.4
Postoperative drainage, mL, (mean ± SD)	724.7 ± 500.9
Postoperative hospital stay, day, (mean ± SD)	8.2 ± 3.4
Complications, n (%)	
Atelectasis	2 (5.9)
Persistent air leak > 7 days	2 (5.9)
Postoperative pneumonia	4 (11.8)
Pleural effusion (reinsertion of chest drain)	0
30-day mortality	0

After the patient is discharged, a minimum of one year of post-discharge telephone follow-up is conducted to inquire about the patient's current condition and compare it with their preoperative state in order to evaluate their prognosis. The patient's satisfaction with the procedure is assessed by categorizing it as excellent (complete resolution of symptoms), good (improvement of symptoms), or unchanged (lack of improvement or worsening of symptoms).

Results

Table 1 presents data from a study involving 34 patients with bronchiectasis. The cohort comprised 8 male and 26 female patients, with an average age of 55.1 years. Notably, 6 patients were smokers, all of whom were male. Additionally, 3 patients were diagnosed with chronic obstructive pulmonary disease (COPD) upon admission, including 1 male and 2 female patients. The predominant clinical symptoms observed before surgery included cough, sputum, hemoptysis, and chest pain. Hemoptysis treatment was the primary surgical indication for 24 patients (70.6%), while 10 patients (29.4%) had failed drug treatment. The lesions were predominantly located in the left lung, with 10 cases (29.4%) in the left upper lobe and 18 cases (52.9%) in the left lower lobe.

The surgical details are summarized in Table 2. The average surgical time for segmentectomy was 157.7 ± 63.4 min. The average intraoperative blood loss was 115.9 ± 107.4 ml. Postoperative tube placement lasted an average of 6.5 ± 2.4 days, with an average drainage volume of 724.7 ± 500.9 ml. The average hospital stay was 8.2 ± 3.4 days.

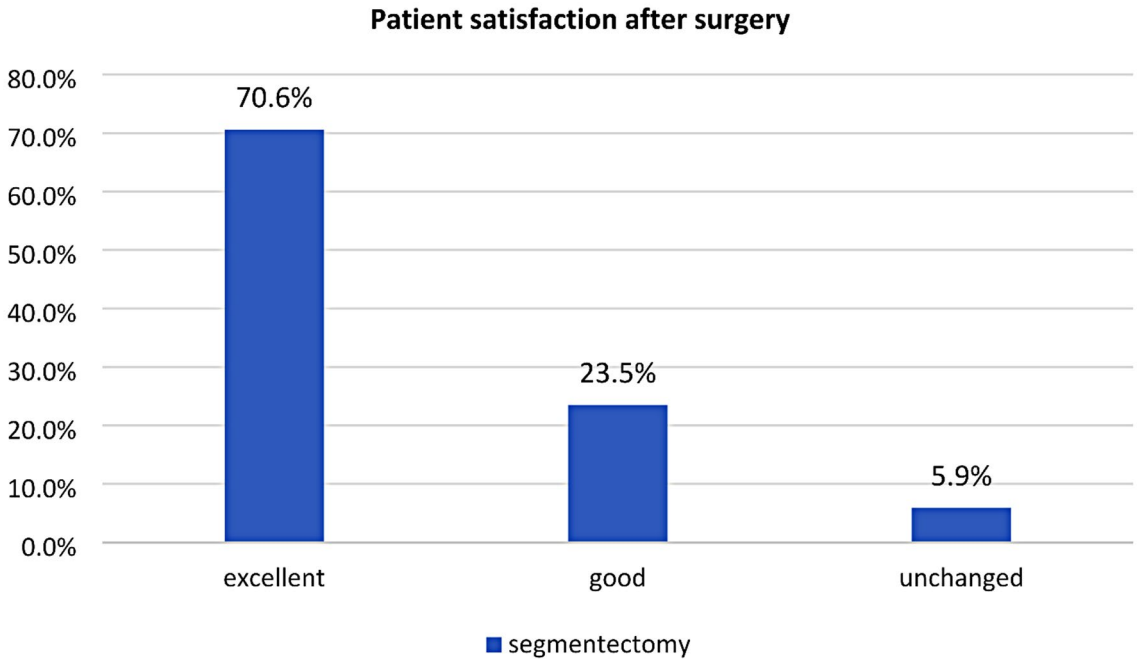

Fig. 3 Patient satisfaction with regard to symptom relief after segmentectomy

Postoperative complications are typically defined as those that arise during the hospital stay or within 30 days following treatment [3]. In this study, no major complications or deaths were observed among the patients. However, 8 patients (23.5%) experienced postoperative complications. Specifically, among the segmentectomy patients, 2 developed pneumothorax and 2 experienced air leaks. Additionally, 4 patients developed pneumonia postoperatively.

All patient follow-up evaluations have been completed, with a minimum follow-up time of one year and an average follow-up time of 14.3 months (range, 13.5–20.6 months). After surgical treatment, 24 out of 34 patients experienced symptom resolution. Eight patients showed improvement compared to their preoperative status. However, two patients showed no improvement or even deterioration (Fig. 3). Both patients who showed no improvement were over 65 years old. Subsequent hospital CT scans indicated that the lesions were located in different lobes of the lung. One patient underwent right upper lobe posterior segment resection. Six months postoperatively, this patient was readmitted with a new bronchiectasis lesion in the lower lobe of the left lung. The other patient underwent left upper lobe apical posterior segment resection. This patient had difficulty with expectoration and required fiberoptic bronchoscope-assisted suctioning. Seven months postoperatively, this patient was readmitted with a new bronchiectasis lesion in the lower lobe of the left lung.

Discussion

Bronchiectasis is a complex condition characterized by permanent and largely irreversible bronchial dilation, often accompanied by recurrent infections [13]. According to the definition of chest imaging by the Fleischner Society, the morphological criteria for thin-slice CT scanning include dilated bronchial lumen with a diameter larger than the cross-sectional area of adjacent pulmonary artery, the lack of bronchial contraction ability, and identification of bronchi within 1 cm of the pleural surface [14]. Current therapeutic approaches typically encompass pharmacological intervention, surgical management, and consideration of interventional therapy for patients presenting with hemoptysis [15].

Bronchiectasis, as a possible infection related bronchial disease, has lesions ranging from one lung segment to bilateral lung tissues. Antibiotic therapy remains the primary treatment for patients with localized bronchiectasis. However, for patients who do not respond to drug therapy or experience recurrent hemoptysis, surgical treatment can remove the permanent damaged lung tissue areas that may serve as reservoirs or foci of recurrent infections. In cases of localized bronchiectasis with recurrent pulmonary infections, segmentectomy can completely excise the bronchiectasis and damaged lung tissue, thereby reducing the risk of subsequent disease recurrence [16, 17]. The surgical approach aims to excise the affected lung tissue extensively while preserving unaffected lung tissue, thereby enhancing

the patient's quality of life. The resection may vary from segmentectomy to pneumonectomy, and at least 2 lung lobes or 6 lung segments must be preserved to maintain postoperative lung function [18].

Based on the 2014 analysis of 86 bronchiectasis patients by Akın Eraslan Balci et al., it is suggested that complete resection is the preferred surgical treatment for bronchiectasis, while incomplete resection may be considered only for palliative management of specific life-threatening symptoms [19]. However, in this study, patients with disease confined to a single lobe of the lung were selected for lobectomy. The excised lung lobe may encompass healthy lung tissue devoid of any pathology. As reported by Jie Dai et al., the excision of the dominant lesion has also been shown to significantly ameliorate symptoms in patients with non-localized bronchiectasis [12]. Based on the above two studies, we conducted an investigation into segmentectomy for the treatment of bronchiectasis limited to one lobe of the lung. The findings indicate that segmentectomy aided by three-dimensional imaging for localized bronchiectasis offers an acceptable rate of postoperative complications and mortality.

Segmentectomy represents a crucial method in thoracic surgery, with its complexity stemming from the intricate anatomy of lung segments and the potential presence of anomalous vessels [20]. The most common variation is that two corresponding arteries supply blood to the same lung segment. To prevent surgical errors, it is crucial to possess a thorough comprehension of pulmonary lobar anatomy and consider the intricate relationships among pulmonary lobar vessels, bronchi, and accurate interlobar planes during surgical procedures [21]. We routinely perform preoperative HRCT scans for each patient, yet inexperienced physicians often struggle to discern existing anatomical variations even with the aid of CT imaging. Consequently, they are compelled to address these unforeseen circumstances during surgical procedures. Not only does it elevate the surgical risk, but it also has the potential to impact the patient's prognosis. With the development of three-dimensional imaging and tomography, medical digital imaging and communication (DICOM) files generated from HRCT scans can be used to create 3D virtual models of the lungs, airways, and vascular system, allowing doctors to more intuitively discover individual anatomical variations. According to a recent study conducted by Giorgio Cannone's team, which involved 11 cases of three-dimensional imaging-assisted for the lung, it has been confirmed that three-dimensional imaging-assisted segmentectomy is precise and practical [16]. Establishing an individualized 3D model before surgery can help simulate the operation in advance. During the operation, it can provide intuitive and accurate guidance for Identifying and locating the pulmonary arteries, veins, and pulmonary lobar bronchi during surgery, shorten the operation time, improve the precision of the operation, reduce bleeding, reduce surgical trauma, and at the same time, reduce the incidence of complications and improve the safety of the operation, which is beneficial to the patient's early postoperative recovery [16, 22, 23].

It is worth noting that, for bronchial arteries originating from the aorta, based on our previous experience, automatic three-dimensional imaging can sometimes be difficult to fully reconstruct. As a result, it appears as a solitary vessel in three-dimensional imaging, making it difficult for young doctors to identify the source of the vessel. However, research has shown that if patients undergo pulmonary angiography, we can use semi-automatic three-dimensional imaging to manually delineate along the aorta on a computer, forming a connection with an isolated bronchial artery [24]. This allows doctors to more easily identify variations and handle corresponding blood vessels during surgery, achieving precise segmentation.

Due to the fact that most patients with bronchiectasis suffer from recurrent infections for a long time, pleural adhesion is a common phenomenon in surgery and is an important factor in determining the feasibility of the operation [25]. Excision of pleural tissue may elevate the risk of hemorrhage and potentially compromise pulmonary parenchyma, thereby impacting the patient's prognosis. Additionally, thickened pleural tissue poses challenges to surgical intervention. Nevertheless, proficient physicians are capable of effectively addressing pleural adhesions while minimizing potential damage to lung tissue and blood vessels. Throughout our study, the average blood loss for all patients with pleural adhesions was approximately 125 ml.

Previous studies have identified prolonged air leak as a common complication following secmentectomy [9]. In our study, however, only 2 out of all segmentectomy patients experienced postoperative air leak, representing approximately 5.9% of the cohort. This achievement is made possible by the utilization of three-dimensional imaging, enabling precise localization of blood vessels and lesions during surgical procedures, thereby minimizing unnecessary damage to lung tissue. One of the patients with postoperative air leak had chronic obstructive pulmonary disease (COPD). During the operation, there was extensive adhesion of the pleura, and according to the results of the CT scan performed before the operation, the lesion was located in two lung lobes. We performed resection of two lung segments (posterior segment of the right upper lung + dorsal segment of the right lower lung) in this patient. Regarding the reason for the patient's postoperative air leakage, we believe that the first reason is that local lung tissue was

damaged during the separation of pleural adhesions, leading to the appearance of postoperative air leakage. And then, compared with the resection of a single segment, the resection of multiple segments requires us to repeatedly separate lung segments, which will cause more damage to lung tissue and increase the possibility of postoperative air leakage. Finally, the patient may have had a poorer lung quality than other patients due to long-term smoking or chronic obstructive pulmonary disease (COPD), and lung tissue is more likely to be damaged. The two patients with postoperative air leaks experienced leakage durations of 6 and 8 days, respectively, and exhibited a few bubbles in the chest when coughing. We managed the air leaks using negative pressure suction. Through active intervention and comprehensive postoperative care, we successfully resolved the air leak issues in both patients.

For patients with postoperative infections, we performed repeated sputum cultures and drug sensitivity tests for each individual, and promptly adjusted the antibiotic treatment plan accordingly. All patients were discharged with effective control of their infections. In comparison to other patients undergoing lung lobe resections, those undergoing lung segment resections also demonstrated significant improvement in postoperative symptoms. At the one-year follow-up, the majority of patients expressed satisfaction with the surgical outcome.

This study is only applicable to patients with focal, localized disease lesions that can be successfully identified on CT and are able to undergo surgery. For patients with disease lesions that are completely involved in a single lung lobe or multiple lung lobes as shown on CT, lobectomy and pneumonectomy are still the preferred options.

The limitations of this retrospective study are as follows: Firstly, the number of patients included was limited, and the sample size was not sufficient to meet the requirements. Secondly, the definition of dominant lesion lacked a specific standard and relied on clinical judgment by experienced surgeons. Ultimately, the follow-up cohort consisted predominantly of elderly individuals with multiple comorbidities and compromised physical well-being. It remains challenging to definitively ascertain the direct correlation between subsequent hospitalization and bronchiectasis. However, it cannot be denied that according to this retrospective analysis, most patients who experienced complications after segmentectomy only had one type of complication, and most patients had their symptoms effectively alleviated.

Conclusion

Three-dimensional imaging-assisted segmentectomy is an effective and feasible treatment option for localized expansion. Postoperative morbidity and mortality rates are acceptable. Most patients experience only one complication after surgery. Follow-up results indicate good surgical outcomes. Most patients experience symptom relief prior to surgery, recurrences are rare.

Abbreviations

HRCT	High resolution computed tomography
COPD	Chronic obstructive pulmonary disease
FEV1	Forced expiratory volume in 1 second

Author contributions

Contributions: (I) Conception and design: J Ge; (II) Administrative support: Z Yan; (III) Provision of study materials or patients: J Ge; (IV) Collection and assembly of data: Z Yan, J Feng; (V) Data analysis and interpretation: Z Yan; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

This study was approved by the review committee of Soochow University.All patients signed written informed consent forms.

Consent for publication

All authors of this study agreed to participate in the study and consent to publication. All individual data included in the study were obtained with the consent of all participants and published.

Competing interests

The authors declare that they have no competing interests.

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