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"Split" combined subsegmentectomy: A case series

Ruopeng Hong[1,2] | Chun Chen[1,2] | Wei Zheng[1,2] | Bin Zheng[1,2] | Chi Xu[1,2] | Guobing Xu[1,2]

[1]Department of Thoracic Surgery, Fujian Medical University Union Hospital, Fuzhou, China

[2]Key Laboratory of Cardio-Thoracic Surgery (Fujian Medical University), Fujian Province University, Fuzhou, China

Correspondence
Chun Chen, Department of Thoracic Surgery, Fujian Medical University Union Hospital, 29 Xinquan Road, Fuzhou 350000, China.
Email: chenchun0209@fjmu.edu.cn

Abstract

Background: Clinically, some specific pulmonary nodules have safe resection margins that are located in multiple subsegments in the center of lung lobe. It is therefore difficult to ensure the resection margins through conventional combined subsegmentectomy or wedge resection, and thus lobectomy is required. For these types of pulmonary nodules, "split" operation was performed to fully inflate the reserved lung tissues on both sides. This study aimed to preliminarily assess the feasibility and safety of "split" operation.

Methods: Cases with these types of pulmonary nodules were selected. Some of the cases were subjected to "split" operation and the operation conditions, including operation time, bleeding amount, length of hospital stay, computed tomography (CT) reexaminations, and pulmonary function, were analyzed.

Results: The "split" operation was performed and successfully completed for seven patients. There was no case of conversion to thoracotomy and the median operation time, bleeding amount, and length of hospital stay were 219 min, 30.0 ml, and 4 days, respectively. No death or pulmonary complications such as pulmonary infection, lung torsion, and bronchopleural fistula occurred, and only one patient had incision fat liquefaction. After 3 months, the median percentage of preserved pulmonary function was 85.8% and a CT scan showed that the reserved lung tissues of the seven patients were well inflated and without obvious imaging findings of atelectasis.

Conclusion: "Split" combined subsegmentectomy can be used as a new and safe operative method for deep pulmonary nodules with safe resection margins involving multiple subsegments in the center of the lung lobe.

KEYWORDS

combined subsegmentectomy, split, three-dimensional reconstruction and simulation, video-assisted thoracoscopy

INTRODUCTION

Segmentectomy, which was first proposed by Jensik et al.[1] in 1973, was not initially accepted by surgeons due to its technical complexity and high risk of long-term air leak. In 1995, a prospective randomized study that was conducted by the North American Lung Cancer Study Group (LCSG) concluded that lobectomy is superior to sublobectomy in terms of recurrence rate and prognosis.[2] Sublobectomy is typically used as an operative method for patients with poor lung function and advanced age.

According to the results of the JCOG0804/WJOG4507L study, sublobectomy of peripheral pulmonary nodules with size ≤2 cm, dominant ground glass opacity (GGO) components, and consolidation tumor ratio (CTR) <0.25 can result in a 5-year recurrence-free survival rate of approximately 100%, a low complication rate, and a small impact on lung function while guaranteeing sufficient resection margins.[3] In practical clinical work, the peripheral pulmonary nodules are mainly composed of GGO components that are primarily processed via sublobectomy, and therefore segmentectomy often becomes the preferential method when there is difficulty in guaranteeing or locating the resection margins by virtue of wedge resection. However, segmentectomy is more difficult to operate than wedge resection. Three-dimensional reconstruction and planning are particularly important for a precise thoracoscopic segmentectomy,[4,5] especially combined subsegmentectomy. Generally, the pulmonary nodules that are distributed on one side of the lung segment are resected in a conical manner. Nevertheless, if the pulmonary nodules have segmentectomy indications but are located deeply, the safe tumor resection margins that involve multiple subsegments in the center of the lung lobe would be hardly covered by the conventional combined subsegmentectomy, and thus lobectomy would be needed. Clinicians may first consider observation or puncture, and then lobectomy after thorough deliberation and agreement by the patient due to the significant impairment of the lung function associated with this method. In this study, a complicated combined subsegmentectomy was conducted for specifically located nodules under the guidance of a three-dimensional reconstruction. In this previously unreported method, the residual lung tissues of the same lung lobe were separated just like mountains separated by a canyon. This operative method was named "split" combined subsegmentectomy, and the short-term results in the perioperative period and postoperative imaging findings were observed after 3 months to preliminarily evaluate the feasibility and safety of the method.

METHODS

Patient selection

Cases with safe resection margins of pulmonary nodules that were located in multiple subsegments in the center of the lung lobe after three-dimensional reconstruction were selected from the same treatment group during February 2019 and June 2021. Routine preoperative examinations included chest thin-slice computed tomography (CT), brain magnetic resonance imaging (MRI), echocardiography, electrocardiogram, color Doppler ultrasound of supraclavicular lymph nodes and whole abdomen, pulmonary function tests, and whole-body bone scan. The preoperative and postoperative staging were performed according to the 8th edition of the TNM Classification for Lung Cancer.[6] Moreover, all intraoperative and postoperative complications and clinical examination data were recorded during the perioperative period.

This study was approved by the Ethics Committee of Fujian Medical University Union Hospital, and the patients were informed about the operative methods and signed the informed consent before operation. All operations were accomplished by experienced chief or associate chief physicians with expertise in lung resection.

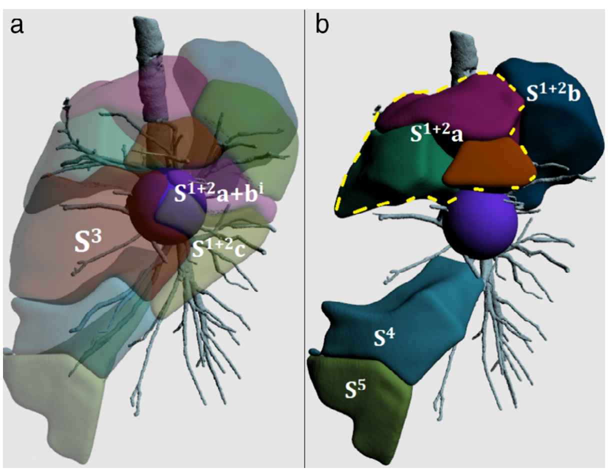

FIGURE 1 (a) Three-dimensional reconstruction for segmentectomy of S3+S1+2c+S1+2a+bi. The blue sphere in the center is the safe resection margins. (b) Surgeons evaluate the resection scheme if there are few remaining healthy lung tissues on one side or a possibility of potential complications

Preoperative three-dimensional reconstruction

Before the operation, the three-dimensional reconstruction was performed for all patients using IQQA-3D system (EDDA Technology) with thin-slice contrast-enhanced CT as the data source. In the system, the lung areas were planned according to the tracheal branches, and the trachea, arteries, and veins of the lung lobe where the target lung segments were located and precisely reconstructed. The positions and ranges of the pulmonary nodules were labeled to divide the lung areas and the resection margin spheres were made 2 cm away from the lesion edge (Figure 1(a)). The reconstruction results were reviewed, and the resection schemes jointly discussed by the experienced surgeons (Figure 1(b)), with an associate director title or above in a single center, and the physicians responsible for three-dimensional reconstruction. The interpretation of the three-dimensional reconstruction is particularly important. First, the sequence of structural treatment of the target lung segment should be evaluated and whether dissection can be performed. Second, it is necessary to assess whether some lung tissue remains after the excision of the target segment structure and whether it is prone to torsion.

Operation processes

After general anesthesia of the patients, the operation was performed via single-port thoracoscopy. An incision of 3.5–4.0 cm was made at the fourth intercostal space at the midaxillary line. If the patient accepted the additional financial costs, a Da Vinci robot was used to conduct the operation.

The proximal and distal ends of blood vessels and bronchi that have a small diameter in the lung segments were often ligated by silk sutures, while the large blood vessels and bronchi were dissected using a linear cutting stapler. In the split operation, the blood vessels and bronchi in the target segments were usually dissociated at the facies mediastinalis and interlobar fissure, and then dissected in the two directions. The structures of the target segments to be severed in both directions should be determined during the preoperative simulation. During the dissociation process, a small amount of lung tissue can be cut if necessary. After the dissection of the arteries, veins and bronchi in the target lung segments were also dissected, the lung tissues below the target lung segments were separated, and a tunnel was made near the pulmonary hilum and along the bronchial surface at the bottom of the target lung segments (Figure 2). Before establishing a tunnel, it is necessary to check whether there are still blood vessels or trachea to reduce bleeding and bronchial fistula.

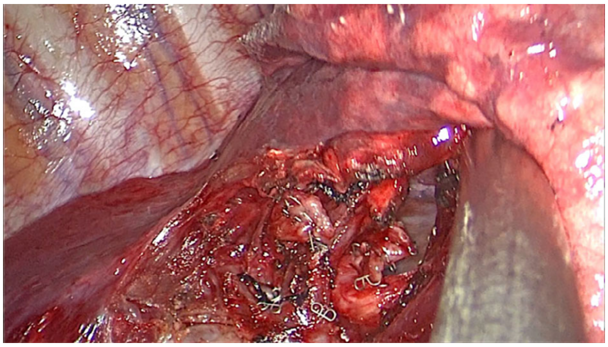

FIGURE 2 An artificial tunnel was made along the bronchial surface at the bottom of the target lung segments

Examples: 1. In robot-assisted thoracoscopic resection of the left upper lobe S^3+S^{1+2}c+S^{1+2}a+b^i(Figure 3(a)), the structures that were divided by operation were as follows: A^{1+2}a+b^i, A^{1+2}c, B^{1+2}a+b^i, B^{1+2}c, V^3b+V^3a+V^{1+2}d, B^3 and A^3. First, A^{1+2}a+b^i, A^{1+2}c, B^{1+2}a+b^i, and B^{1+2}c were dissociated from the oblique fissure and dissected, and V^3b +V^3a+V^{1+2}d, B^3 and A^3 were dissociated from the anterior mediastinum and then dissected. Subsequently, the oblique fissure and anterior mediastinum were penetrated between the bronchial surface and the bronchial cut ends B^{1+2}a+b^i, B^{1+2}c and B^3 in the left upper lobe to form a tunnel below the target lung segments and above the trachea. 2. In the single-port thoracoscopic resection of the right upper lobe S^1+S^2b+S^3a(Figure 3(b)), the operated structures were as follows: V^1a, A^1a, A^1b, A^3a, B^1, A^2b, B^3a, and B^2b. V^1a, A^1a, A^1b, A^3a and B^1 were dissociated and dissected from the superior mediastinum, and A^2b, B^3a and B^2b were dissociated and dissected from the interlobar fissure. Second, the lobar fissure and anterior mediastinum were penetrated between the bronchial surface and bronchial cut ends B^1, B^3a, and B^2b in the right upper lobe to form a tunnel below the target lung segments and above the trachea.

The inflation-deflation method was employed under 100% oxygen and 20–25 cmH_2O pressure, and the structures were stripped along the inter-segmental planes using the combined dimensional reduction method[7] and an ultrasonic knife. Later, the inter-segmental planes were processed by the incision linear cutting stapler below the tunnels passing the target lung segments when

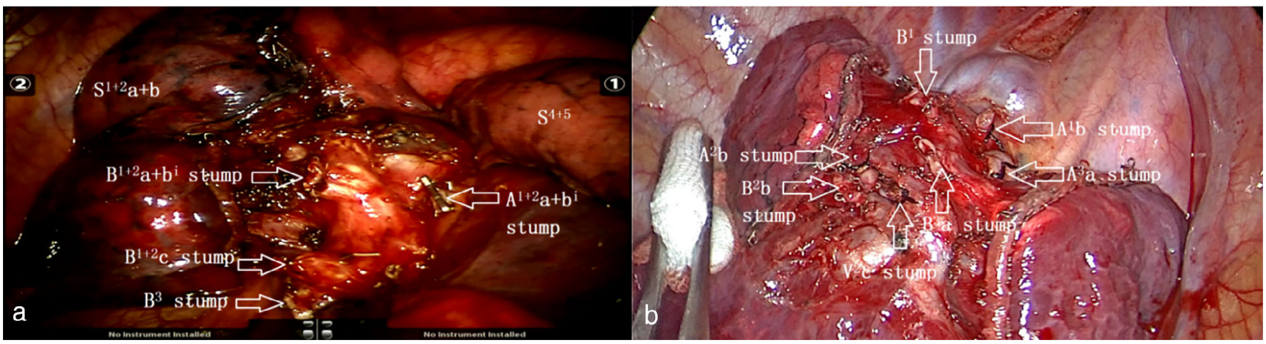

FIGURE 3 (a) The remain lung tissue after LS^3+S^{1+2}c+S^{1+2}a+b^i resection. (b) The remain lung tissue after RS^1+S^2b+S^3a resection

TABLE 1 Characteristics of patients received "Split" combined subsegmentectomy

Patient	Age (years)	Sex	Position	Tumor size (mm)	CTR	Area of resection	Pathology results
1	55	Male	RUL	7	0	S^1+S^3a	MIA
2	52	Male	RUL	11	0	S^1b+S^3a	MIA
3*	61	Male	LUL	15	0.4	S^3+S^{1+2}c+S^{1+2}a+b^i	MIA
4	41	Female	RUL	11	0.27	S^1b+$S^1$$a^i$+$S^2$b+$S^3$a	MIA
5	77	Male	LUL	13	0	S^3+S^{1+2}c	MIA
6	68	Female	LUL	16	0.4	S^3+S^{1+2}c	MIA
7	32	Female	RUL	8	0	S^1+S^2b+S^3a	MIA

Abbreviations: CTR, consolidation tumor ratio; LUL, left upper lung; MIA, microinvasive adenocarcinoma; RUL, right upper lung. *Robotic segmentectomy.

they became linear two-dimensional planes. The inter-segmental planes on one side were cut by stretching the target lung segments toward the other side, and then the inter-segmental planes on the other side were cut using the linear cutting stapler.

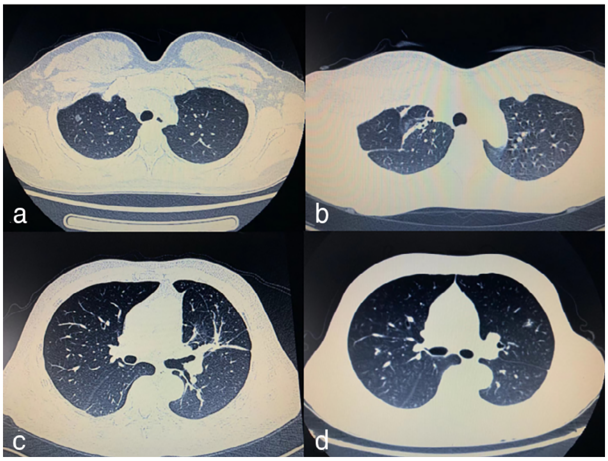

FIGURE 4 (a) The preoperative lung CT scan for RS^1+S^{2}b +S^{3}a. (b) The postoperative lung CT scan for RS^1+S^{2}b+S^{3}a after 3 months. (c) The postoperative lung CT scan for LS^3+S^{1+2}c+S^{1+2}a+b^i after 3 months. (d) The preperative lung CT scan for LS^3+S^{1+2}c+S^{1+2}a+b^i. Arrows mark pulmonary nodules

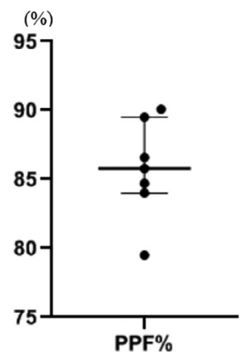

FIGURE 5 Percentage of postoperative preserved pulmonary function after "split" combined segmentectomy

Atelectasis, pulmonary torsion, and incomplete expansion of lung caused by bronchial angulation should be prevented.

When no bronchopleural fistula was found during the intraoperative examination, two drainage tubes (24–28-F drainage tube and 8-F ultrafine drainage tube) were inserted in the chest cavity.

The postoperative drainage amount was the sum of the closed drainage tube and the ultra-fine drainage tube. The timing of removing the closed drainage tube should meet the following requirements: (i) no pulmonary air leakage, (ii) good pulmonary reinflation, and (iii) the ultrafine drainage tube should drain smoothly. After the closed drainage tube was removed, the ultrafine drainage tube was kept until the liquid output was less than 150 ml for a 24-hour period.

Statistical methods

SPSS 22.0 software was adopted for statistical analysis. The data that did not meet normal distribution or conformed to skewed distribution were expressed as median and inter-quartile range [$M(P_{25}$–$P_{75})$].

Follow-up

The postoperative lung CT and the pulmonary function were re-examined after 3 months. After surgery, the percentage of preserved pulmonary function (PPF%) was calculated using the following formula: (FEV1 after surgery/FEV1 before surgery)100 (%).

RESULTS

Seven patients from the same treatment group received the "split" operation in a single center. The operation was

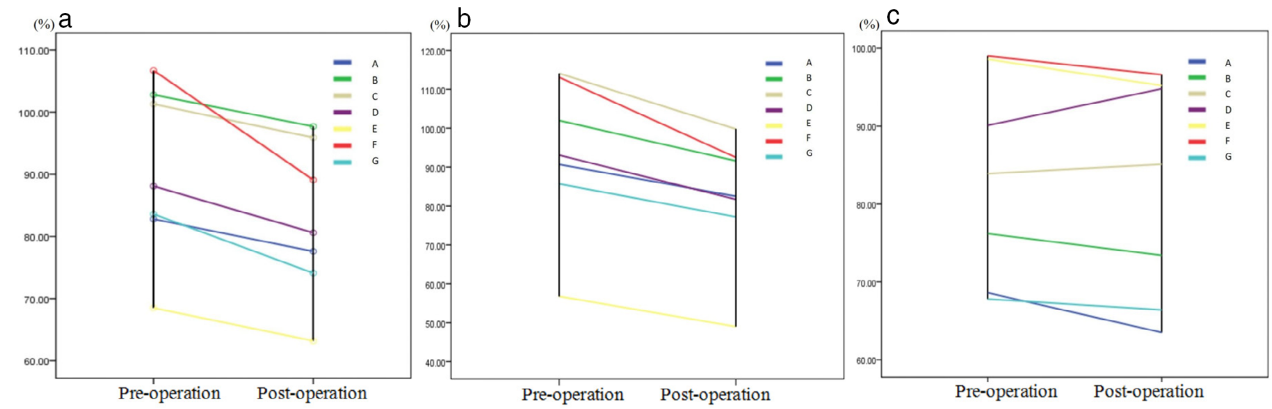

FIGURE 6 (a) Comparison of the FVC% of "split" combined segmentectomy between preoperation and postoperation. (b) Comparison of the FEV1% of "split" combined segmentectomy between preoperation and postoperation. (c) Comparison of the DLCO% of "split" combined segmentectomy between preoperation and postoperation. FEV1, forced expiratory volume in 1 second; FVC, functional vital capacity; DLCO, diffusion capacity of carbon monoxide. A.RS1+S3a. B.RS1b+S1ai+S2b+S3a. C.LS3+S1+2c+S1+2a+bi. D. RS1b+S3a. E.LS3+S1+2c. F. LS3+S1+2c. G.RS1+S2b+S3a

successfully completed in all seven cases, including the four males and three females, with a median age of 55 years (range 32–77). Three cases received a lesion resection on the left upper lung and four cases on the right upper lung. There was one case of left upper lung $S^3+S^{1+2}c+S^{1+2}a+b^i$ which was resected using the Da Vinci robot, and the other six cases underwent single-port thoracoscopy, including one case of right upper lung S^1+S^3a, one case of right upper lung S^1b+S^3a, one case of right upper lung $S^1b+S^1a^i+S^2b+S^3a$, two cases of left right upper lung $S^3+S^{1+2}c$, and one case of right upper lung $S^1+S^2b+S^3a$ (Table 1). The data were gathered and analyzed as follows: median tumor diameter 11.0 mm (range 7.0–16.0, P_{25}–P_{75} 8.2–15.0), median operation time 219.0 min (range 166.0–354.0, P_{25}–P_{75} 177.0–264.0), median bleeding amount 30.0 ml (range 20.0–100.0, P_{25}–P_{75} 20.0–50.0), postoperative median extubation time of closed drainage tube 2.0 days (range 2.0–3.0), median postoperative drainage amount 375.0 ml (range 290.0–1035.0, P_{25}–P_{75} 335.0–855.0), and postoperative median length of hospital stay 4.0 days (range 3.0–6.0, P_{25}–P_{75} 3.0–6.0). All patients were smoothly discharged, and there were no death cases or pulmonary complications, such as pulmonary infection, lung torsion, and bronchopleural fistula. Incision fat liquefaction occurred in one case after discharge, and the incision was sutured by a young doctor. During the follow-up period, there was no pleural effusion, secondary admission or secondary operation. The postoperative lung CT scan was reviewed after 3 months, and the imaging findings showed well-inflated reserved lung tissues and the absence of obvious atelectasis (Figure 4). The lung function was examined 3 months after surgery for median PPF%: 85.8% (range 79.5–90.1%, $P_{25}P_{75}$ 84.0–89.5%) (Figure 5). Figure 6 shows a comparison of the FVC%, FEV1%, and DLCO% of "split" combined segmentectomy between preoperation and postoperation. Compared with the preoperative pulmonary function, the overall trend of postoperative pulmonary function was downward, but the downward trend was acceptable (Figure 6).

DISCUSSION

Lobectomy and systematic lymph node dissection can serve as standard procedures for early-stage non-small-cell lung cancer (NSCLC). The feasibility of these approaches was reported in 1995 by the North American LCSG based on a prospective multicenter randomized controlled study that was conducted on sublobectomy versus lobectomy for the treatment of early-stage NSCLC.[2] Retrospective studies have revealed the absence of a noticeable difference in survival rate between segmentectomy and lobectomy in patients with early-stage NSCLC.[8,9] For deep pulmonary nodules with segmentectomy indications, further investigations are required to improve our understanding of pulmonary function preservation and reduction of operation-related complications while also ensuring a sufficient resection margin of a tumor. This study complied with the provisions of NCCN Guidelines Version 4.2021 on segmentectomy and is also supported by the results of JCOG0804/WJOG4507L[3] as powerful evidence.

Considering that all lung segments, subsegments, and sub-subsegments are irregular cone-shaped, Wu WB et al. have reported the concept of "cone-shaped segmentectomy".[10] Routine segmental resection, such as single lung segment, combined subsegment, and combined multisegment, often tends toward one side. Despite the size of resected target lung tissues, the lobe is separated into two parts: one for reservation and the other for resection. However, for deep pulmonary nodules with less possibility of wedge resection and safe resection margins that are located in multiple subsegments in the center of lung lobe, such as RS^2b, RS^3a, RS^1 or the center of LS^3 and $LS^{1+2}c$, the tumor cannot be completely removed through single lung segment, combined subsegment, or combined multisegment. However, the safe resection margins cannot be ensured even if one side of the lung segment is resected, and the resection range is expanded with linear cutting stapler while also processing inter-segmental planes to concurrently remove the pulmonary nodules.

"Split" combined subsegmentectomy that is proposed for the first time cannot be easily understood but can be explained. The lung lobe is separated into three consecutive parts, followed by resection of the middle part, and the remaining lung tissues, like mountains in the canyon, are located on both sides. The following basic requirements should be met for this operation: (i) tumor diameter ≤ 2 cm and GGO composition >50%, (ii) safe resection margins of pulmonary nodules involving multiple located subsegments in the center of the same lung lobe, and resection margins of tumor that cannot be ensured after wedge resection and combined subsegmentectomy, (iii) resection margins ≥2 cm or more than the tumor diameter in any direction, and (iv) intraoperative frozen pathology (−) of hilar lymph nodes. As for the decision related to the surgical method, the cost of the robot requires paying additional fees. The selection of surgical methods was mainly decided by the position of pulmonary nodules and the scope of plan resection. If we disregard the cost, the accuracy and stability of the Da Vinci robot surgery is the better choice.

The results of the three-dimensional and quantitative reconstruction can be provided by the IQQA-3D image interpretation and analysis system.[11] The range of the target lung segments that needs to be resected is planned according to resection margin spheres. In the patients who underwent $LS^3+LS^{1+2}c$ resection in this center, pulmonary nodules were located at the $LS^{1+2}a+b$, $LS^{1+2}c$, LS^3 and LS^{4+5} borders, and at resection margin spheres that were partially covering LS^{4+5} and $LS^{1+2}a+b$. Therefore, wedge resection of partial LS^{4+5} and LS^{1+2} lung tissues was needed while also cutting the inter-segmental planes to ensure the resection margins. The crucial procedure of the operation is to precisely interpret the structure of the target lung segment before the operation, paying attention to the variations in branches of blood vessels and bronchi, searching for the superficial anatomical structure that is the closest to the target lung segment, evaluating the operative approaches and processing sequence of structures, and making efforts to dissect into the deep structures. All target lung segments are separated through two anatomical planes, and the crucial step is to penetrate the two anatomical planes above the trachea and below the target lung segment to establish an artificial tunnel. Care should be taken to avoid separating too many lung tissues, and the reversed lung volume per unit should not be less than the volume of the lung subsegment to avoid atelectasis or torsion. The need for accurate structural interpretation, precise and stable operation, and high-quality operative regimens is emphasized to reduce anatomical blindness and avoidable injury to lower the probability of atelectasis and lung torsion. Before simulating the "split" operation, it is recommended to re-evaluate the resection scheme if there are few remaining healthy lung tissues on one side or a possibility of potential complications. In this study, "split" combined segmentectomy was not conducted on bilateral lower lobes and the right middle lobe, which is related to the operative approach, anatomical complexity, safe resection margin of tumor, and difficulty of operation. Therefore, there is a need for a more detailed and comprehensive operation planning, favorable three-dimensional reconstruction and simulation, and precise operative regimens.

Compared with simple segmentectomy, multiple complex inter-segmental planes may be attributed to lung segments with complex anatomical structure that require corresponding complex procedures.[12] Simple segmentectomy was reported by Li et al.[13] and showed that 26 cases are needed to master uniportal thoracoscopic segmentectomy and 52 cases are necessary to achieve proficiency. Cheng et al.[14] proposed that an experienced surgeon can achieve a relatively stable level after 33 cases for uniportal thoracoscopic segmentectomy. 219.0 min (median) are required at the beginning of the application of this kind of operation. We believe that with the increasing number of successful cases, the surgical time will be even shorter in the future. Considering that complex inter-segmental planes usually exist in the "split" combined segmentectomy, the precise obtention and appropriate process of the inter-segmental planes is particularly important.

The highly consistent inter-segmental planes can be achieved by the inflation–deflation method and the intravenous injection of indocyanine green fluorescence.[15] A comparison was made between a linear cutting stapler versus electrocoagulation in the processing of inter-segmental planes in numerous studies. Electrocoagulation has a main disadvantage that is due to a higher incidence of postoperative air leak compared with the cutter stapler.[16,17] With respect to the methods of obtaining and processing inter-segmental planes, our research team considered that after dissecting the bronchi and arteries of the target lung segments, favorable and clear inter-segmental planes can be obtained by the inflation–deflation method followed by burning with an ultrasonic knife and cutting with a cutter stapler. This approach is safer and simpler, and is called the combined dimensional reduction method. As reported by Zheng et al.,[7] the combined dimensional reduction method contributes to a simpler and more accurate operation during segmentectomy, which is expected to become a feasible and effective single-port thoracoscopic segmentectomy. Otherwise, the remaining lung tissues may shrink in the case of direct resection by linear cutter stapler, which is not conducive to stretching. Nomori et al.[18] proposed that the median PPF% in the segmentectomy group was 93.2% (P_{25}–P_{75} 82.8–89.1%) within 6 months after surgery. Although no statistical comparison could be made, their data was similar, and the lung function was preserved by segmental resection and within an acceptable range.

In the present study, due to the short period and small sample size, the specific impact on survival was not evaluated. In addition, bias existed when the control group was set up for a propensity matching analysis.

In conclusion, "split" combined segmentectomy can offer a novel and safe procedure for removing deep pulmonary nodules with safe resection margins involving multiple subsegments in the center of the lung lobe. Despite the acceptable perioperative results, additional data are required to evaluate its influence on pulmonary function, quality of life, and long-term survival of patients.

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CONFLICT OF INTEREST

No potential conflicts of interest are disclosed.

ORCID

Ruopeng Hong https://orcid.org/0000-0003-1088-2222
Bin Zheng https://orcid.org/0000-0001-8429-5384

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