

Thoracoscopic right middle lobe subsegmentectomy: A single-center, retrospective review



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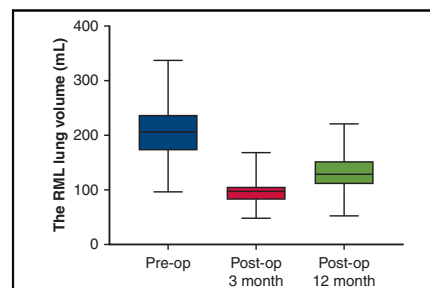
ABSTRACT

Objective: The right middle lobe subsegmentectomy (including multisubsegmentectomy and subsubsegmentectomy) has never been reported. This study aimed to describe a thoracoscopic right middle lobe subsegmentectomy.

Methods: This retrospective study included 94 patients who underwent thoracoscopic right middle lobe subsegmentectomy between August 2018 and February 2021. All procedures were performed with the help of the preoperative 3-dimensional computed tomography bronchography and angiography.

Results: Ninety-four patients underwent thoracoscopic right middle lobe subsegmentectomy. The median operative time was 56 minutes (range, 35-86 minutes) and median blood loss was 86 mL (range, 50-150 mL). The median duration of chest tube retention was 2.5 days (range, 1-4 days). There were neither cases of postoperative right middle lobe torsion nor instances of perioperative death. The median size of the tumor in the resected segment was 1.3 cm (range, 1.1-1.8 cm). The median margin was 3.3 cm (range, 2.9-4.3). There were 88 cases of lung cancer and 6 cases of benign lesions. The median number of N1 lymph nodes sampled was 3 (range, 2-4). No lymph node involvement was observed postoperatively. No recurrence or mortality was observed during the median follow-up period of 26 months (range, 6-36 months).

Conclusions: Thoracoscopic right middle lobe subsegmentectomy is feasible and safe. It may be valuable to preserve the lung parenchyma in patients with noninvasive lung cancer, multiple lung cancer, and benign diseases. Long-term lung function, survival, and cancer-free data are being collected. (JTCVS Techniques 2022;13:229-36)



The subsegments of right middle lobe.

CENTRAL MESSAGE

The thoracoscopic right middle lobe subsegmentectomy was feasible and safe in our experience.

PERSPECTIVE

The right middle lobe subsegmentectomy, multi-subsegmentectomy, and subsubsegmentectomy have never been reported. The function-preserving sublobectomy method for thoracoscopic middle lobe subsegmentectomy is a simple, safe, and effective procedure with clear procedural steps. Thus, it may be valuable to preserve lung parenchyma.

▶ Video clip is available online.

Lobectomy by video-assisted thoracoscopic surgery has been proven to be safe and effective for the treatment of non-small cell lung cancer in the early stage for approximately 30 years. However, as high-resolution computed

tomography (HRCT) is commonly used for routine health checkups, many ground-glass opacities (GGOs) have been identified. For these lesions, especially for those less than 2 cm and a consolidation tumor ratio of less than 50%, a lobectomy would result in the sacrifice of a relatively large amount of lung parenchyma and a reduction in lung function. Segmentectomy is indicated more frequently with noninferior long-term outcomes and even improved survival benefits, especially for nonsolid tumors with GGO.^{1,2} The volume of the right middle lobe (RML) is the smallest among all lung lobes, and the benefits of sublobe resection are considered marginal. There is little published data regarding RML segmental anatomy and segmental resection techniques.^{3,4} The objective of this study was to report our experiences with thoracoscopic RML subsegmentectomy, including multisubsegmentectomy and subsubsegmentectomy, using 3-dimensional computed tomography bronchography and angiography (3D-CTBA). The purpose was to determine the feasibility

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Abbreviations and Acronyms

3D-CTBA	= 3-dimensional computed tomography bronchography and angiography
CT	= computed tomography
FEV1	= forced expiratory volume in 1 second
GGO	= ground-glass opacity
HRCT	= high-resolution computed tomography
RML	= right middle lobe

and safety of this method based on the largest case series to date.

METHODS

Patients

Between August 2018 and February 2021, 94 of 5012 patients underwent thoracoscopic RML subsegmentectomy (including multisubsegmentectomy and sub-subsegmentectomy). Patient data were prospectively collected and retrospectively reviewed. Written informed consent was obtained from each patient before surgery. This retrospective study was approved by the Ethics Committee of our hospital (no. 2020-206, 29/4/2020).

Selection Criteria

The specific candidates were as follows: patients with a GGO dominant (GGO $\geq 50\%$) peripheral pulmonary nodule of ≤ 2 cm that might be preinvasive lung cancer, or patients with possible benign lesions. Patients who were not suitable for lobectomy because of compromised pulmonary function were also appropriate candidates for this parenchyma-sparing procedure. Patients with multiple GGOs involving RML were excluded. Patients with GGO close to the visceral pleura, which is suitable for wedge resection, were excluded. Patients with GGO located in the inner one-third of the lung where a safe oncologic margin cannot be guaranteed were also excluded (Figure 1). The surgical margin was designed to be > 2 cm or larger than the maximum diameter of the tumor. The newly proposed histologic classification system and the eighth edition of the TNM staging system were adopted for histologic typing and surgical pathologic staging, respectively. We used the volume of the residual RML (%) to reflect the function of RML.

Computed Tomography (CT) Volumetry Data

CT scan data of the patients were collected. The lobe-specific lung volume was measured with software (Mimics Software; Materialise).

Operative Procedure

Preoperative planning. HRCT scans were routinely performed and carefully reviewed. The CT scans were all performed using a 64-slice CT scanner. Two sets of images were formed and saved individually onto discs. These were contiguous 1-mm slices (1-mm set) and 1-mm slices every 10 mm. Other preoperative evaluations included blood tests, cardiopulmonary function tests, as well as radiologic investigations of the brain, bone, and abdomen. Anatomic variations and positional relationships were analyzed using 3D-CTBA. No preoperative CT-guided hook wires were used for the localization.

Surgical techniques. The RML segmentectomy (RS⁴, RS⁵) is already reported.⁴⁻⁶ The RML subsegmentectomy, however, is never reported. Here, we use an RS⁵a + RS⁵bi subsegmentectomy as a representative of our case series. The patient was 58 years old. HRCT revealed a 9-mm GGO in RML (Figure 2, A). A positron emission

tomography scan showed no high uptake in the GGO and no lymph node involvement. Lung cancer could not be excluded. A wedge resection was not considered because it was located deep inside the lung tissue and was not palpable. Preoperative 3D-CTBA showed that the bronchus was a trifurcation type (B⁴, B⁵a, B⁵b),⁷ and B⁵b was further divided into B⁵bi and B⁵bii (Figure 2, B). GGO was located between B⁵a and B⁵bi. A⁵ had 2 branches (A⁵a and A⁵b), and A⁵b was further divided into A⁵bi and A⁵bii (Figure 2, C). The branching pattern of the vein was a 3-stem type (V⁴a, V⁴b + V⁵a, V⁵b), and the GGO was located in the drainage area of V⁵a (Figure 2, D). The measurements on the preoperative 3D-CTBA showed the margin from the tumor to the intersegmental plane (between RS⁴ and RS⁵a + RS⁵bi) was 25.69 mm and the margin from the tumor to the intersegmental plane (between RS⁵a + RS⁵bi and RS⁵bii) was 38.10 mm (Figure 2, E). Both margins were more than 2 cm or larger than the diameter of the tumor. An RS⁵a + RS⁵bi multisubsegmentectomy could guarantee a safe oncologic margin. Usually, this surgery starts from tracking the A⁵ and B⁵ along the interlobe artery; however, in this case, the horizontal fissure was found undeveloped, and the A⁵a and A⁵bi arose far from the interlobe artery, thus making it difficult to track and dissect. The first step of this operation was the incision of the mediastinal pleura, avoiding splitting of the lung parenchyma in the horizontal fissure. V⁴b + V⁵a was identified. Then, V⁵a was dissected and ligated. The lymph node (station 13) was dissected for frozen sections as well as for better exposure.

Commonly, the lung is ventilated after all the bronchovascular structures of the target segment are resected. The method we used here was different from the others. After the vein was blocked, we requested the anesthesiologist to ventilate the lung using 100% oxygen without isolation and anatomical transection of the bronchus and artery. The alveoli in which the pulmonary circulation continues (preserved segments) can perform gas exchange and absorb oxygen (hypoxia zone). Alveoli with no pulmonary circulation (target segments, in which the vein is cut) cannot be involved in gas exchange and retain oxygen inside (hyperoxia zone). The border between hyperoxia zone (inflation area) and hypoxia zone (deflation area) defines the intersegmental plane. After 10 minutes of waiting for the visualization of the intersegmental plane, the demarcation line was marked by electrocautery (Figure 2, F), and the intersegmental planes were tailored with a stapler. An RS⁵a + RS⁵bi multisubsegmentectomy was performed (Video 1). Pathologic examination on frozen sections confirmed minimally invasive adenocarcinoma and no metastasis to the station 13 lymph nodes (because the procedure for lymph node sampling is quite easy, it is omitted in this video). The operative time was 47 minutes. The patient was discharged on postoperative day 2. For all patients, the surgical margin was immediately measured (Figure 3). Lobectomy and systematic lymph node dissection were performed if lymph node metastasis was confirmed on intraoperative frozen sections.

Safe Margin Guarantees

The adequacy of a safe margin is the primary concern in sublobectomy. In our research, the safe oncologic margin was confirmed from 3 aspects. The first aspect was based on preoperative imaging assessment. Here, we used a virtual “safe-margin balloon.” This is a virtual “balloon” with the tumor as the center point and a radius of 2 cm. This “balloon” must be completely within the target subsegment. In Video 2, we display the details of the “safe-margin balloon.” This is the core step in the process of surgical planning. The second aspect is the measurement of the actual dimension of the resection margin, which will be much more reassuring. In Figure 3, we display the measurement of the actual dimensions of the specimen. The third aspect is the intraoperative frozen section. All margins were examined by pathologic examination on the intraoperative frozen sections. These 3 aspects could guarantee an adequate preoperative, intraoperative, and postoperative oncologic margin.

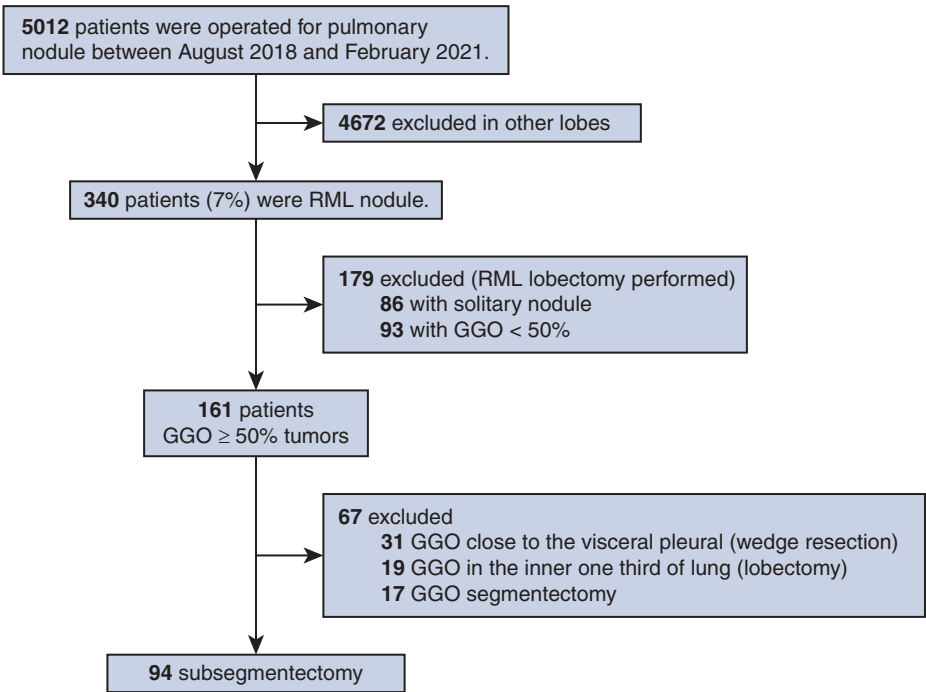


FIGURE 1. A flow diagram detailing the number of patients. *RML*, Right middle lobe; *GGO*, ground-glass opacity.

Statistical Analysis

Data were analyzed using SPSS (version 22.0; IBM Corp).

RESULTS

Patient characteristics are shown in [Table E1](#). Surgical types of RML are listed in [Table E2](#). Ninety-four patients underwent RML subsegmentectomy. In detail, 44 patients underwent RS⁴a subsegmentectomy, 24 underwent RS⁴b subsegmentectomy, 16 underwent RS⁵a subsegmentectomy, 4 underwent RS⁵b subsegmentectomy, 2 underwent RS⁵a + RS⁵bi subsegmentectomy, 2 underwent RS⁴b + RS⁵a multisubsegmentectomy, and 2 underwent RS⁴ai subsegmentectomy.

All procedures were performed by thoracoscopy. There was no conversion to a lobectomy. Perioperative outcomes are presented in [Table E3](#). The median operative time was 56 minutes (range, 35-86 minutes), and the median blood loss was 86 mL (range, 50-150 mL). The median duration of chest tube retention was 2.5 days (range, 1-4 days). Postoperative morbidity was 1% (1/94, prolonged air leakage >5 days). There were no cases of RML atelectasis postoperatively. There were no instances of perioperative death. The median size of the tumor in the resected segment was 1.3 cm (range, 1.1-1.8 cm). The median margin was 3.3 cm (range, 2.9-4.3). Pathologic examination on intraoperative frozen sections revealed that radical resection was achieved with free surgical margins in all patients. The histologic subtypes were as follows: 88 cases of primary lung cancer (48 cases of adenocarcinoma in situ,

AIS; 40 cases of minimally invasive carcinoma, MIA) and 6 cases of benign lesions (4 cases of hamartoma and 2 cases of granuloma). For patients with preinvasive diseases (adenocarcinoma in situ, minimally invasive carcinoma), N1 was sampled. The median number of N1 lymph nodes sampled was 3 (range, 2-4). No lymph node involvement was observed postoperatively. No recurrence or mortality was observed during the median follow-up period of 26 months (range, 6-36 months).

Fifty-two of the 94 patients reached the follow-up to 1 year. Their CT volumetry data were collected, and the variations were analyzed by a box and whisker plot ([Figure 4](#)). Compared with RML lobectomy, RML subsegmentectomy could preserve lung volume to varying degrees. In our case, the volume of RML was 236 mL, contributing to 13.67% of the entire right lung volume. Three months after surgery, the volume of the remnant RML was reduced to 79 mL, contributing to 5.98% of the entire right lung volume. One year after surgery, the volume of the remnant RML was slightly recovered to 101 mL, contributing to 5.82% of the whole right lung volume ([Figure 5](#)).

DISCUSSION

It is believed that pulmonary function can be better preserved by sublobe resection.⁸ Evidence from encouraging outcomes, such as the randomized study JCOG-0802, has been increasing.² As a sublobe resection, wedge resection is also considered to be sufficiently effective in patients with radiologically noninvasive tumors⁹; however, it was

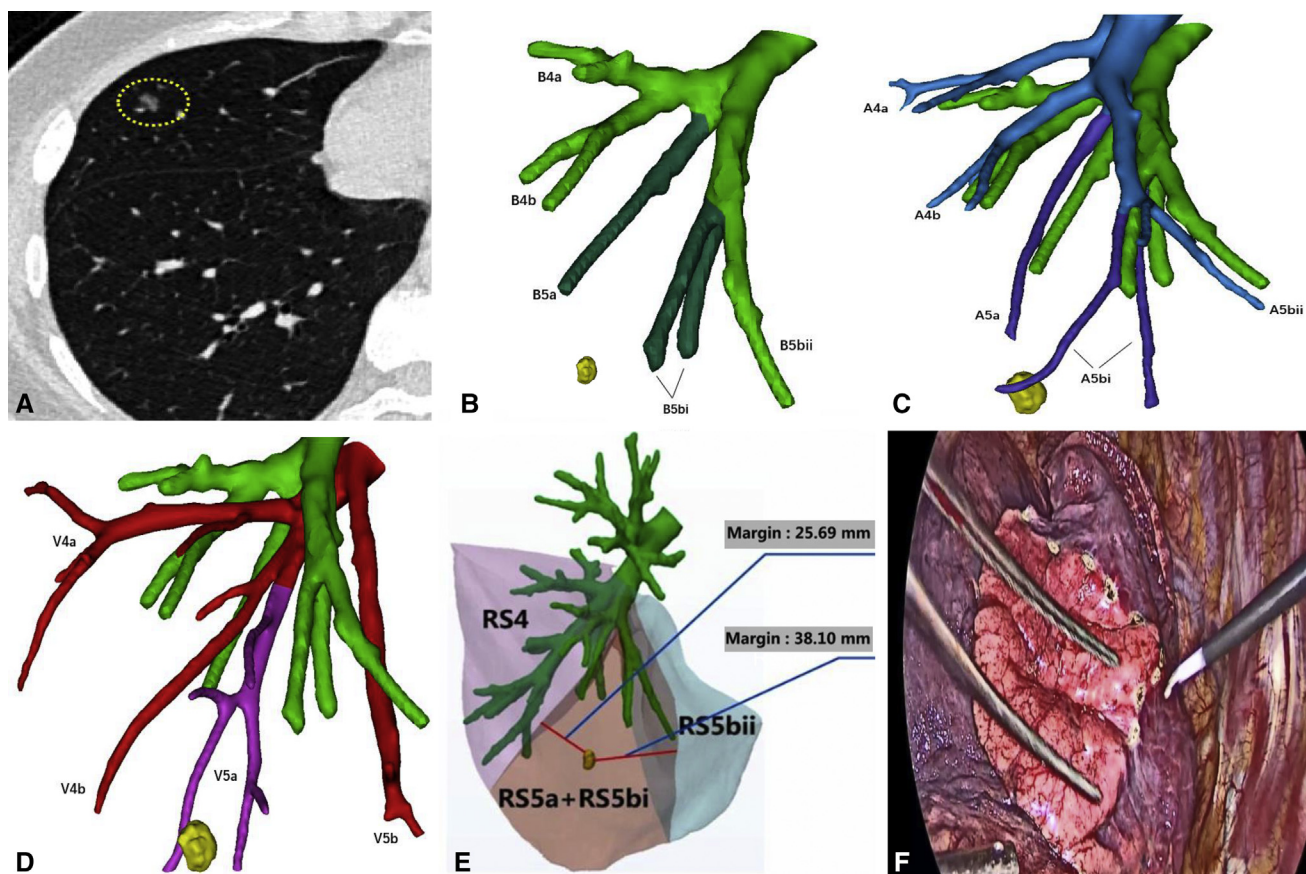


FIGURE 2. The preoperative 3D-CTBA helps to identify the target segmental vessels and bronchi and their positional relationships (a $RS^5a + RS^5bi$ multisubsegmentectomy as an example). A, The location of the GGO in RML. B, The 3 branches of the B^{4+5} (B^4 , B^5a , B^5b) arise at almost the same horizontal level. The B^5b further divided into B^5bi and B^5bii . The GGO locates between B^5a (S^5a) and B^5bi (S^5bi). C, The A^5a and A^5bi go along the B^5a and B^5bi , respectively. They are the target-arteries of $RS^5a + RS^5bi$. The GGO is located between the 2 arteries. D, The GGO is located in the drainage area of V^5a , which functions now as the “intrasegmental” vein of the $RS^5a + RS^5bi$. E, By the measurements on the preoperative 3D-CTBA, the margin from the lesion to the intersegmental plane between RS^4 and $RS^5a + RS^5bi$ is 25.69 mm; the margin from the lesion to the intersegmental plane between $RS^5a + RS^5bi$ and RS^5bii is 38.10 mm. F, The intersegmental planes were visualized and marked by electrocautery. 3D-CTBA, 3-Dimensional computed tomography bronchography and angiography; GGO, ground-glass opacity; RML, right middle lobe.

not included in our study. There are several reasons for this. First, it is difficult to secure an adequate surgical margin in wedge resection, especially when the tumor is located deep inside the lung and is not palpable. Margin distance in wedge resection has been proven to affect local recurrence,¹⁰ and segmentectomy appears to be a better choice for sublobe resection.¹¹ Second, wedge resection does not respect the intrapulmonary anatomy, and 1 or more segments may be resected without attention on the bronchovascular anatomy. Anatomical segmentectomy emphasizes anatomical dissection with individual ligation of the hilar structures. It does not transgress the intersegmental planes. The ventilation/perfusion ratio in the remaining lung tissues does not interfere. Third, it is impossible to sample the intrapulmonary lymph node (N1) by wedge resection; however, by segmentectomy, any perivascular nodes could be removed along the way while dissecting the vessels.

Intrapulmonary lymph node retrieval may play a role in evaluating the outcome of pN0 patients.¹² For all the aforementioned reasons, wedge resection was not included in our study.

RS^4 and RS^5 were very small segments. Nagashima analyzed the bronchovascular patterns of RML using 3D-CTBA.⁴ Yajima and colleagues³ reported the first 2 cases of RML segmentectomy in 2018. We reported the VVBA method for RS^4 segmentectomy in 2020 and RS^5 segmentectomy in 2021.^{5,6} Here, we summarized 94 cases of RML subsegmentectomy (RS^4a , RS^4b , RS^5a , and RS^5b), multisubsegmentectomy ($RS^4b + RS^5a$, $RS^5a + RS^5bi$), and subsubsegmentectomy (RS^4ai). To date, this is the first, largest, and most complex case series reported on RML in the literature.

Segmentectomy is uncommonly performed for RML, and one of the main reasons is that the overall contribution

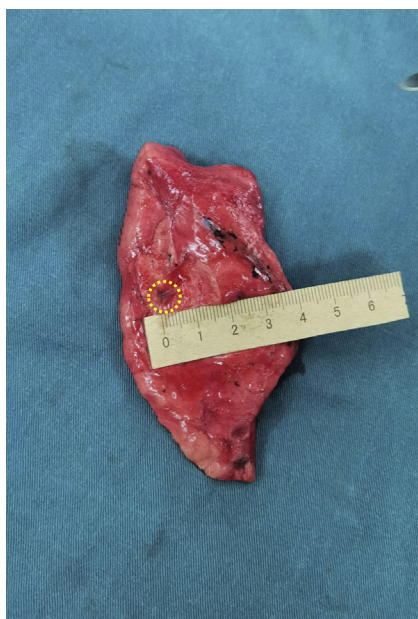
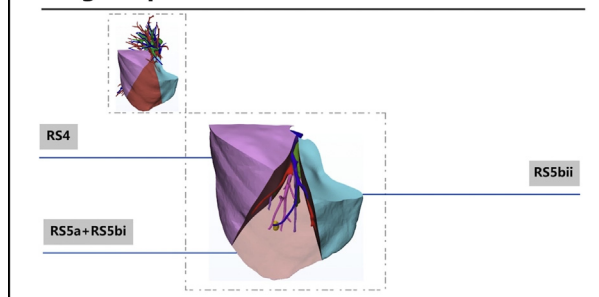


FIGURE 3. The measurement of the actual specimen dimension. The yellow dotted line indicates the location of GGO (9 mm in diameter). The surgical margin is almost 4 cm. GGO, Ground-glass opacity.

of RML to the total lung volume (and lung function) is much less than that of the other lung lobes. The relative volume of RML is generally considered to be approximately 10% of the total lung volume⁴; in our patients, however, volumes varied between 9% and 21% (Table E3). In addition, patients with multiple GGOs may need several synchronical (sub)segmentectomies to achieve complete resection, and it is important to preserve lung volume in each resection. Subsegmentectomy for RML is a valuable lung-sparing procedure. To demonstrate the advantages of the lung parenchyma sparing strategy, the forced expiratory volume in 1 second (FEV1) is always recommended; however, some authors may have reservations about the benefit of segmentectomy in terms of preservation of lung function. They concluded that it saves only a few percent of preoperative FEV1 and offers mild postoperative to small long-term functional benefits over lobectomy.⁸ Another limitation of FEV1 is that it cannot reflect lobe-specific lung function.

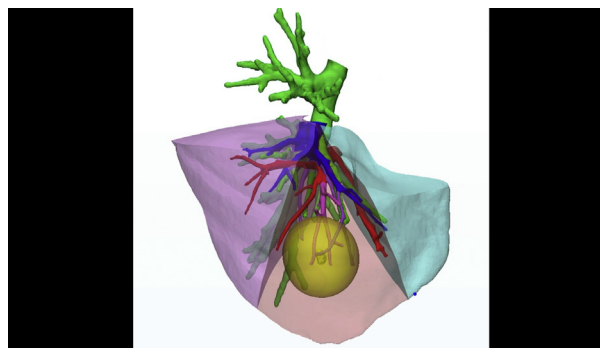
The method we used for subsegmentectomy of RML was different from the others. It represents a pathophysiologic, valid, and technologically less demanding alternative to traditional anatomical (sub)segmentectomy. It differs from the wedge resection in 2 ways. First, the auxiliary procedures like CT wire insertion before wedge resection is omitted. Using this method, we can locate the invisible and unpalpable GGOs in an entirely noninvasive way: the preoperative 3D-CTBA helps us to identify the target vessels penetrating the lesions. By blocking the target vessels, circulation of the target (sub)segment is interruption. The

Surgical plan -- Vein



VIDEO 1. Analyzing the anatomic variations and positional relationships of the subsegmental vessels and bronchi by carefully reviewing the 3D-CTBA (a RS^{5a} + RS^{5bi} multisubsegmentectomy as an example). A single-blocking video-assisted thoracoscopic surgery RS^{5a} + RS^{5bi} multisubsegmentectomy is performed. A 58-year-old female patient with no comorbidities was diagnosed with ground-glass nodules located in the RML (9 mm). Usually, this surgery started from tracking the A⁵ and B⁵ along the inter-lobe artery, however, the horizontal fissure is found hypoplastic. Additionally, the A^{5a} and A^{5bi} arise far from interlobe artery, the tracking and dissection of them seems difficult. The surgery was therefore initiated by incising the anterior mediastinal pleura, avoiding inessential splitting of the lung parenchyma by stapler. The V^{4b} + V^{5a} was identified first. Then the V^{5a} was dissected and ligated. The lymph node (station 13) was dissected for a frozen section as well as a better exposure. Then, we require the anesthesiologist to ventilate the lung using 100% oxygen. During the 10-minute wait for visualization of intersegmental plane, the N2 lymph nodes (station 4, 7) are sampled. Then, the intersegmental planes were tailored using a stapler. The frozen section pathological examination confirmed minimally invasive adenocarcinoma and no metastasis to the station 13 lymph nodes (because the procedure for lymph node sampling is quite easy, it is omitted in this video). The systemic hilar and mediastinal lymph node sampling was not performed. The operative time was 47 minutes. The patient was discharged on postoperative day 2. Video available at: [https://www.jtcvs.org/article/S2666-2507\(22\)00196-1/fulltext](https://www.jtcvs.org/article/S2666-2507(22)00196-1/fulltext).

alveoli in which the pulmonary circulation continues can perform the gas exchange and absorb oxygen (deflation zone). Alveoli with no pulmonary circulation (target



VIDEO 2. A virtual “safe-margin balloon” is used for the preoperative evaluation of safe-margin. This is a “balloon” with the tumor as center points and 2 cm as radius. This “balloon” must be totally within the target subsegment. Video available at: [https://www.jtcvs.org/article/S2666-2507\(22\)00196-1/fulltext](https://www.jtcvs.org/article/S2666-2507(22)00196-1/fulltext).

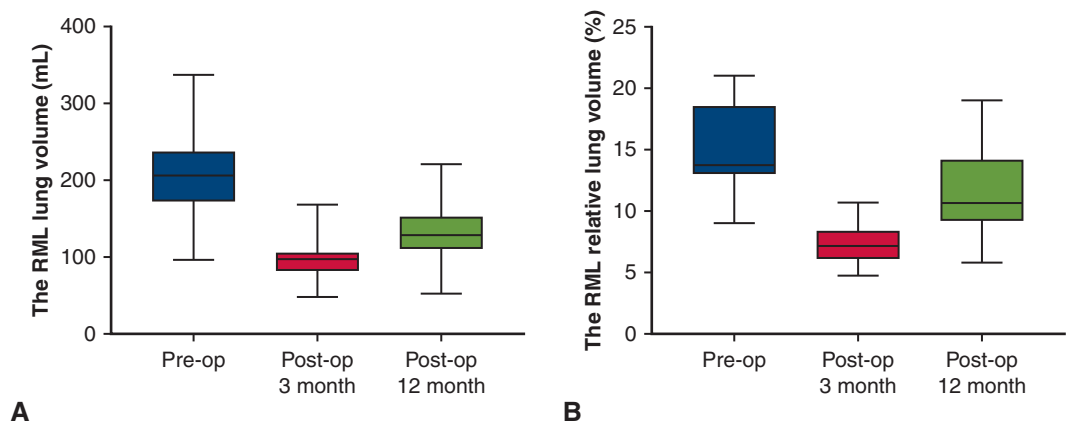


FIGURE 4. The variations of the volume in the residual RML. A, the variations of the volume (milliliters); and B, the variations of the volume (%). The lower and upper borders of the box represent the 25th and 75th percentiles, and the middle horizontal line represents the median. RML, Right middle lobe.

segments) cannot be involved in gas exchange and retain oxygen inside the inflation zone. The border between the inflation and deflation areas defines the border of the target subsegment. A parenchymal division is accomplished with a stapler along the demarcation line. Another difference is that the wedge resection does not respect the intrapulmonary anatomy, one or more segments may be resected without attention to the bronchovascular anatomy. The remaining lung tissue, because of the interrupt of circulation, may be unfunctional (Video 3). Our method is a balancing strategy between wedge resection and anatomical segmentectomy. It uses the ease and rapidity of wedge resection as well as the accuracy and precision of anatomical

segmentectomy. It respects the intrapulmonary anatomy and does not transgress intersegmental planes. This greatly simplifies the procedure of anatomical segmentectomy and makes complex procedures such as subsegmentectomy, multisubsegmentectomy, and subsubsegmentectomy. We have designed a prospective, randomized controlled study comparing subsegmentectomy and lobectomy for RML. We expect to have conclusive results on survival and pulmonary functions within 5 to 10 years.

In our case series, no RML atelectasis was found, and we did not take any measures (like fixing the remnant RML with other lobes) to prevent it. We believe that this is relevant to our method, in which only the vein or artery is

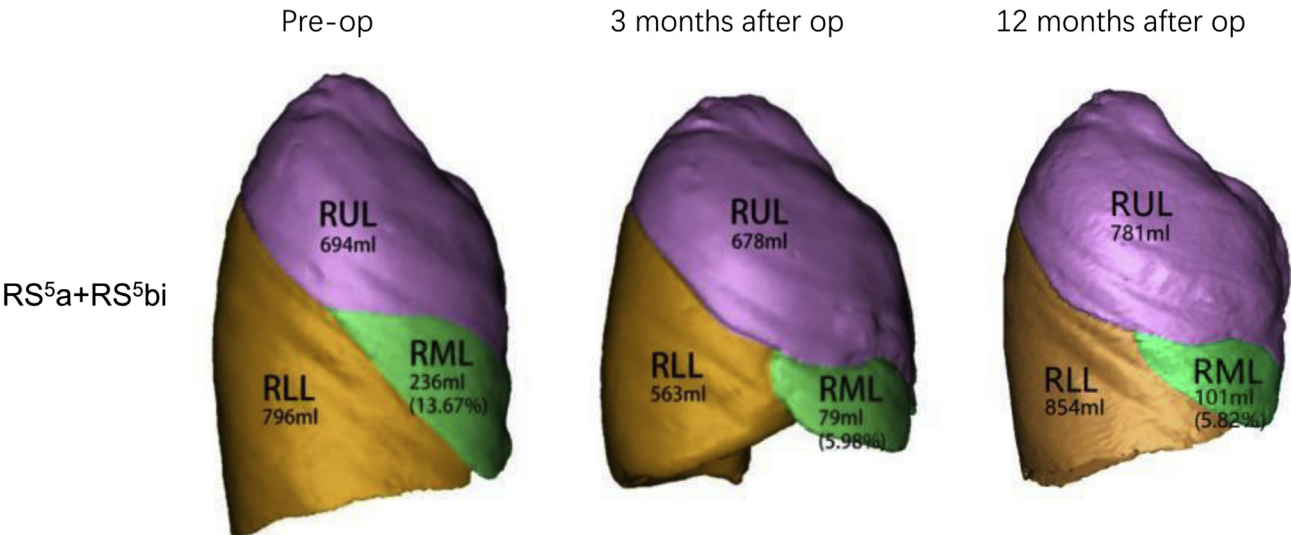
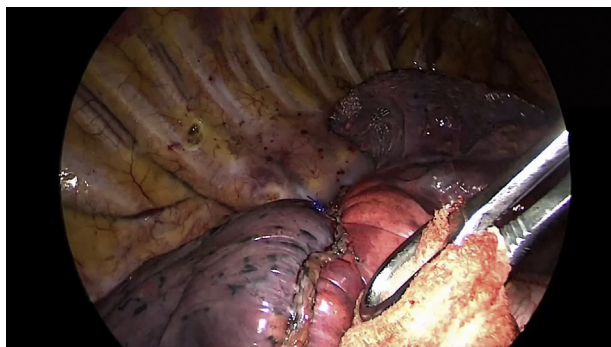


FIGURE 5. We use the volume of the residual RML to reflect the function of RML. The volume of the RML is 236 mL, contributing to 13.67% of the whole right lung volume. Three months after surgery, the volume of the remnant RML is reduced to 79 mL, contributing to 5.98% of the whole right lung volume. One year after surgery, the volume of the remnant RML is slightly recovered to 101 mL, contributing to 5.82% of the whole right lung volume. RUL, Right upper lobe; RLL, right lower lobe; RML, right middle lobe.



VIDEO 3. A wedge resection is performed on right lower lobe. The lung tissue around the stapling line is always inflated. This is because the circulation in this region is interrupted by stapler. The alveoli with no pulmonary circulation cannot be involved in gas exchange and retain oxygen inside. This part of lung tissue is unfunctional. Video available at: [https://www.jtcvs.org/article/S2666-2507\(22\)00196-1/fulltext](https://www.jtcvs.org/article/S2666-2507(22)00196-1/fulltext).

isolated, and the parenchyma is resected without isolation of the bronchus. Less is more.

Study Limitations

This study was retrospective and lacked a comparison group. However, as thoracoscopic RML subsegmentectomy is rarely reported worldwide, we believe that it is still important to provide more options for thoracic surgeons. Another weakness of this study is the lack of long-term survival and cancer-free data. We have started a comparative study to delineate the merits of this method.

CONCLUSIONS

Although the volume of RML ranks the smallest among all lung lobes, it can still be subsegmented. In our experience, RML thoracoscopic subsegmentectomy is feasible and safe. Our method enables anatomic subsegmentectomy to be performed in a simple manner. Long-term lung function, survival, and cancer-free data are being collected.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: thoracoscopic, subsegmentectomy, right middle lobe

TABLE E1. Patient's characteristics

Characteristic	Total N = 94
Age, y	
Range	33-73
Median	47
Male/female	30/64
Chief symptom	
No symptom	88
Chest pain	2
Chest distress	4
Comorbidity	
No	68
Hypertension	10
Diabetes	2
Hypertension and diabetes	6
Chronic hepatitis B	6
Hypothyroidism	2
History of malignancy	
No	92
Breast cancer	1
Salivary gland cancer	1

TABLE E3. Perioperative outcomes

Variables	Total N = 94
Operative time, min	
Median	56
Range	35-86
Blood loss, mL	
Median	86
Range	50-150
Chest tube duration, d	
Median	2.5
Range	1-4
Postoperative complications	
Air leakage	1
RML atelectasis	0
Tumor size, cm	
Median	1.3
Range	1.1-1.8
Margins size, cm	
Median	3.3
Range	2.9-4.3
RML lung volume %	
Median	16%
Range	9%-21%
Histologic subtypes	
Benign lesions	6
AIS	48
MIA	40
N1 lymph node sampled	
Median	3
Range	2-4
Pathologic TNM stage of lung cancer (88 cases)	
0	48
IA1	21
IA2	19

RML, Right middle lobe; AIS, adenocarcinoma in situ; MIA, minimally invasive carcinoma; TNM, tumor, node and metastasis.

TABLE E2. Surgical types of RML subsegmentectomies

RML subsegmentectomies	No. of cases
RS4a	44
RS4b	24
RS5a	16
RS5b	4
RS5a + RS5bi	2
RS4b + RS5a	2
RS4ai	2

RML, Right middle lobe.