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Risk factors for postoperative complications in patients with pulmonary tuberculosis

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Abstract

Background The risk factors associated with postoperative complications following pulmonary resection in individuals with tuberculosis remain incompletely understood.

Methods We conducted a retrospective analysis of baseline data—including sex, age, BMI, comorbidities, previous COVID-19 status, smoking history, respiratory function, ASA grade, affected lung lobe, and operative factors—in patients who underwent surgical treatment at Wuhan Pulmonary Hospital between January 2018 and September 2022.

Results This study included 204 patients diagnosed with pulmonary tuberculosis (PTB) who underwent surgery at our hospital between January 2018 and September 2022. Of these, 138 cases (67.6%) were male and the median age was 49 years. Postoperative complications were observed in 63 patients, representing an incidence rate of 30.9% (63/204). The most commonly reported complications were prolonged air leak (PAL; 29 cases), postoperative pleural effusion (PE; 23 cases), post-resectional space (PRS; 27 cases), pneumonia (9 cases), and hemorrhage (5 cases). Multivariate analysis identified male sex (odds ratio [OR]: 2.322, 95% confidence interval [CI] 1.015–5.313, $p=0.046$), severe adhesion grade (OR 4.304, 95% CI 1.710–10.830, $p=0.002$), and longer operative time (OR 1.007, 95% CI 1.003–1.011; $p=0.001$) as significant risk factors for postoperative complications. For PAL specifically, male sex (OR 4.003, 95% CI 1.111–14.421, $p=0.034$), severe adhesion grade (OR 3.943, 95% CI 1.313–11.839, $p=0.014$), and longer operative time (OR 1.005, 95% CI 1.001–1.009, $p=0.016$) were significant risk factors. Significant risk factors for postoperative PE included severe adhesion grade (OR 6.078, 95% CI 1.318–28.026, $p=0.021$) and longer operative time (OR 1.005, 95% CI 1.000–1.010, $p=0.043$). Blood transfusion (OR 4.493, 95% CI 1.270–15.888, $p=0.020$) was identified as a significant risk factor for PRS.

Conclusions Male gender, severe adhesions, and prolonged operative time were identified as significant risk factors for postoperative complications. Specifically, risk factors for postoperative PAL included male sex, severe adhesions, and longer operative time. Severe adhesions and prolonged operative time were also associated with an increased risk of postoperative PE. Intraoperative blood transfusion emerged as a significant risk factor for PRS. This finding helps us identify problems, improve operations, and reduce potential postoperative complications.

Keywords Postoperative complication, Risk factor, Pulmonary tuberculosis, Surgery

Introduction

Tuberculosis (TB), caused by the bacterium Mycobacterium tuberculosis, is transmitted through airborne particles expelled by infected individuals. It primarily affects the lungs and remains a major global health concern, ranking among the leading causes of illness and death

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worldwide. In 2021, an estimated 10.6 million people were diagnosed with TB, and the disease claimed ~ 1.6 million lives [1]. Without proper treatment, TB carries a high mortality rate—around 50% [2]. However, with the standard 4–6 month regimen of anti-TB drugs), approximately 85% of patients can achieve full recovery. Surgery continues to play a significant role in TB management [3]. It can effectively remove destroyed lung tissue, reduce bacterial load, eliminate infectious sources, alleviate systemic symptoms, and control life-threatening complications, such as massive hemoptysis. Surgical intervention is particularly indicated for cases involving cavitary TB, tuberculous cysts, multidrug-resistant TB, severe hemoptysis, destroyed lungs, and tuberculous bronchopleural fistulas that are unresponsive to medical therapy. Despite its benefits, surgical treatment for TB carries a risk of complications, including postoperative prolonged air leak (PAL), intraoperative hemorrhage, pleural effusion (PE), postoperative residual pleural spaces (PRS), lung infections, and, in some cases, mortality. Compared to patients with lung cancer, those with TB generally face higher surgical risks. A study by Mehran and Deslauriers reviewing operative outcomes between 1955 and 2005 reported overall morbidity at 8.49% and mortality rates ranging from 0 to 12% [4, 5]. Advancements in surgical technology and increased surgical experience have contributed to a decline in postoperative complications and mortality rates associated with TB surgery [6, 7]. While thoracic adhesions were once considered a relative contraindication for thoracoscopic surgery in TB patients, the evolution of minimally invasive techniques has expanded its use. Video-assisted thoracic surgery (VATS), in particular, has been associated with reduced postoperative pain, shorter hospital stays, less inflammatory immune response, and improved respiratory outcomes compared to traditional open surgery (OS) [8].

Nevertheless, the relationship between postoperative complications and various risk factors—both patient-related and surgical—in individuals with pulmonary tuberculosis (PTB) undergone pulmonary resection remains unclear. Accurate identification of these risk factors and appropriate preoperative interventions may help reduce or prevent postoperative complications. In this study, we conducted a retrospective analysis to investigate the risk factors associated with postoperative complications in PTB patients who underwent surgical treatment, and we explored personalized treatment strategies tailored to each type of complication.

Materials and methods

Study design

This study is a single-center retrospective review of postoperative complications of patients with PTB. All included patients were diagnosed with tuberculosis based on pathological and microbiological evidence, in according with the World Health Organization's *Treatment of Tuberculosis: Guidelines, Fourth Edition (2014).* A multidisciplinary team—including pharmacologists, radiologists, pulmonologists, and thoracic surgeons—was responsible for determining preoperative and postoperative medication regimens as well as surgical indications. Between January 2018 and September 2022, a total of 215 PTB patients underwent surgical treatment at our hospital. Of these, 8 patients were excluded due to incomplete clinical data or inconsistent surgical methods, and an additional 3 were excluded due to lack of follow-up. Ultimately, 204 patients were included in the final analysis (see flowchart in Fig. 1):

1. Inclusion criteria: (1) patients diagnosed with PTB. (2) Underwent surgery at our hospital. (3) Normal cardiopulmonary function and no surgical contraindications. (4) Completion of a full course of anti-TB therapy and availability of follow-up data.

2. Exclusion criteria: (1) patients diagnosed with drug-resistant TB or other pulmonary diseases. (2) Prior lung surgery at another institution. (3) Refusal or inability to tolerate surgery. (4) Incomplete clinical data.

Data and group

The data in this article were exported from the medical record data department and manually verified against the hospitalization case system; no interpolation techniques were applied to the data. Our study's data set includes basic information, medical history, laboratory tests, examinations, and surgical data of patients (Table 1). The normal reference range for BMI is $18.5 \leq \text{BMI} < 25.0$. ASA grading scores were calculated based on the American Society of Anesthesiologists'method [9]. We collected all patients'previous COVID-19 infections status and divided into different levels according to WHO standards. We collected data on all patients'previous COVID-19 infection status and classified them into different levels according to WHO standards. Smoking was categorized into three types based on the WHO smoking index (number of cigarettes smoked per day × number of years smoking): heavy smoker, moderate smoker, and light smoker. Pulmonary function test reference values were determined using the European Respiratory Society/American Thoracic Society's method [10]. We collected respiratory function parameters, such as the forced expiratory volume in 1 s as a percentage of the forced vital capacity (FEV1%). Patients were classified according to the extent of pulmonary lesions and adhesions to surrounding tissues observed in preoperative chest CT scans. Adhesion involving less than 50% of the affected lung was classified as mild adhesion, while

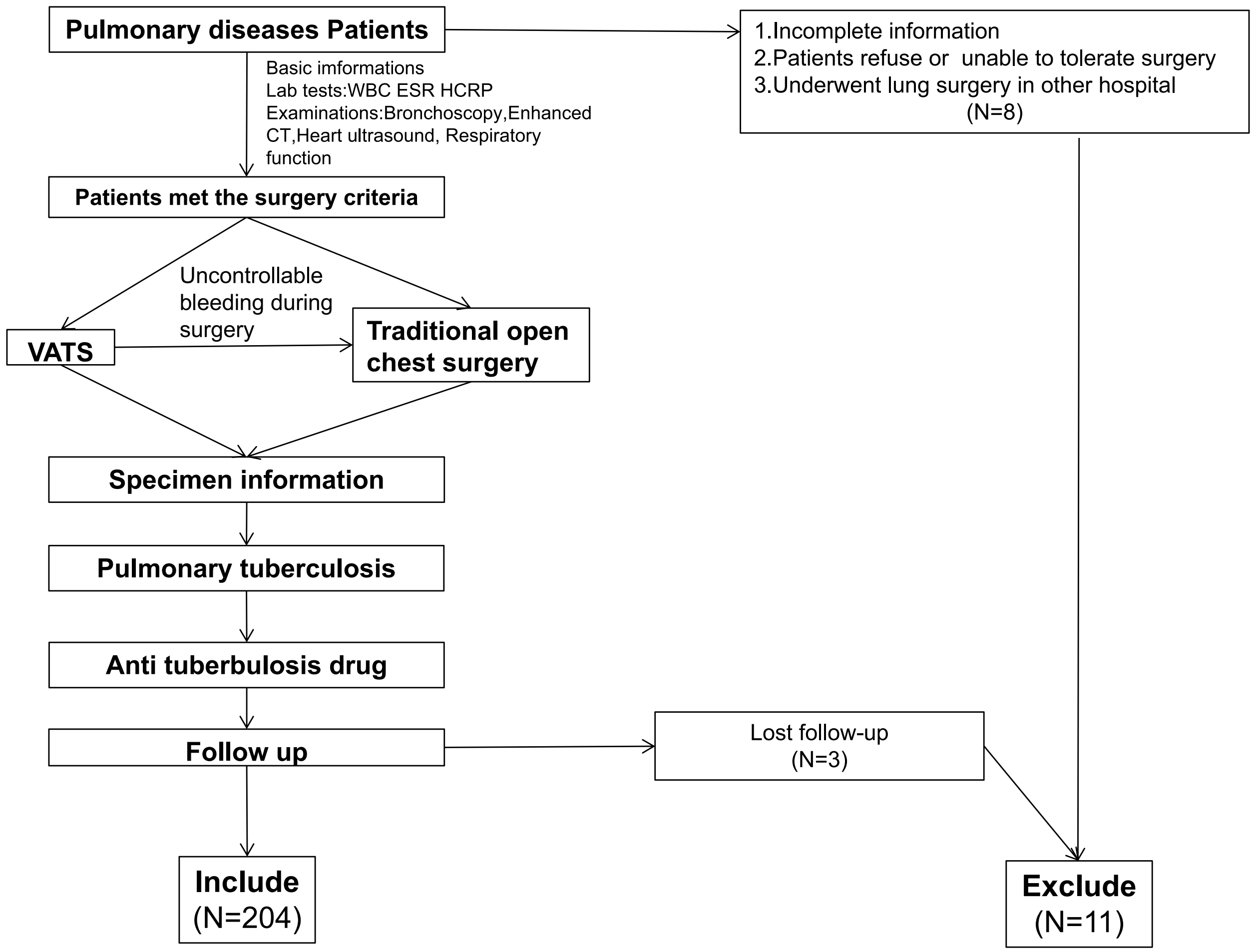

Fig. 1 Flow chart of this study

adhesion involving more than 50% was classified as severe adhesion. In addition, we measured the maximum diameter of the lesion on CT scans and recorded comorbidities, such as diabetes mellitus and hypertension. We also documented whether patients underwent preoperative bronchial artery embolization.

The surgical information includes details on surgical approaches, procedures, operative times, operative bleeding, blood transfusions, postoperative drainage, postoperative hospital stay, postoperative pain scores, total hospital stay, and complications, such as PAL, postoperative PE, PRS, hemorrhage, and lung infections in patients with pulmonary tuberculosis.

The surgical approach was categorized into two categories: VATS (video-assisted thoracoscopic surgery), which involved one to three small incisions each, each less than 3 cm in length; and OS (thoracotomy), which required direct visualization with rib spreading and a wound length greater than 8 cm. The operative procedures were further subcategorized into segmentectomy, lobectomy, wedge resection, combined lobectomy and segmentectomy, and pneumonectomy.

Patients were divided into two groups based on the presence or absence of postoperative complications. This complications included PAL, postoperative PE, PRS, thoracic hemorrhage, pulmonary infection, bronchopleural fistula, delayed wound healing, chylothorax, pulmonary embolism, and deaths, all of which were recorded and graded according to the Clavien–Dindo criteria [11, 12]. PAL was defined as persistent air leak from the chest tube, excluding bronchopleural fistula in an unhealed lung wound, lasting for 2 week post-surgery. Postoperative PE was defined as imaging that suggested pleural effusion after surgery. PRS was defined as a residual cavity identified on chest imaging after chest tube removal. Postoperative thoracic hemorrhage referred to active bleeding from the thoracic cavity. Pulmonary infection was defined as infected residual lung with laboratory results confirming postoperative pulmonary infection in bacterial-infected patients exhibiting at least four of

Table 1 Patient characteristics

Sex (male/female)	138/66
Age, years, median (range)	49 (14–73)
BMI, kg/m^2,median (range)	21.9 (17.5–26.4)
ASA grade (2/3)	132/72
Previous COVID-19 status	
Uninfected	82
Asymptomatic infections	89
Mildly infected	33
Smoking (Index)	
Heavy smoker(Smoking Index ≥ 400)	19
Moderate smoker(Smoking Index between 200 and 400)	58
Light smoker(Smoking Index ≤ 200)	127
FEV1%, median (range)	85.2 (63.1–92.5)
Comorbidities	
DB	27
HP	22
Hemoptysis (yes/no)	86/118
Preoperation BAE (yes/no)	11/193
ATB Time, days, median (range)	30 (0–810)
Adhesion grade (Mild/Severe)	120/84
Maximum diameter of lesion, cm, median (range)	5 (2–20)
Location	
Right/left	92/112
WBC, × 10^9/L, median (range)	5.64 (2.31–19.32)
ESR, mm/h, median (range)	13 (1–117)
HCRP, mg/L, median (range)	1.75 (0.05–129.60)
Operative approach	
VATS/TOS	148/56
Operative procedure	
Sublobectomy (Seg/wedge)/Lobectomy (Lob/Lob + Seg/Lob + wedge/Pneumo)	72/132
Operative times, min, median (range)	210 (25–610)
Operative bleeding, ml, median (range)	200 (5–6000)
Transfer blood (yes/no)	31/173
Postoperative complications	63
PAL	29
PE	23
PRS	27
Hemorrhage	5
Pneumonia	9
Bronchopleural fistula	1
Delayed wound healing	1
Chylothorax	1
Pulmonary embolismb	1
Cause of death	2
Pneumonia	1
Acute myocardial infarction	1

the following five signs: (1) white blood cell count > 15 × 10^9/L; (2) temperature > 38 °C; (3) cough and sputum; (4) rales on lung auscultation; and (5) exudative lung lesions visible on chest X-ray or CT.

Complications management

1. PAL: (1) Clavien–Dindo grade I: clinical observation and pulmonary function exercises, prolonged chest tube retention); (2) Clavien–Dindo grade II: negative chest pressure suction; and (3) Clavien–Dindo grade IIIa: thoracic injection of adhesives.
2. Postoperative PE: (1) Clavien–Dindo grade I: clinical observation or diagnostic evaluation only; intervention not indicated (drainage only through existing drainage tube); (2) Clavien–Dindo grade II: medical management indicated (e.g., diuretics); and (3) Clavien–Dindo grade IIIa: Image-guided drain placement/thoracentesis including drain replacement indicated.
3. PRS: (1) Clavien–Dindo grade I: clinical observation; (2) Clavien–Dindo grade II: negative chest pressure suction, thoracic injection of adhesives; and (3) Clavien–Dindo grade IIIa: image-guided drain placement.
4. Pneumonia: (1) Clavien–Dindo grade I: clinical observation or diagnostic evaluation only; intervention not indicated except for nebulizers, expectorants, or lung physiotherapy (e.g., postural drainage); (2) Clavien–Dindo II: medical management indicated (e.g., antibiotics); (3) Clavien–Dindo grade III: bronchoscopic aspiration, tracheal puncture; and (4) Clavien–Dindo grade V: mechanical ventilation indicated.
5. Hemorrhage: (1) Clavien–Dindo grade I: controllable with compression only; (2) Clavien–Dindo grade II: blood transfusion or medical management indicated; (3) Clavien–Dindo grade IIIa: surgical hemostasis under local anesthesia or endoscopic and radiological intervention hemostasis indicated; and (4) Clavien–Dindo grade IIIb: intervention under general anesthesia indicated (hemostasis).
6. Postoperative bronchopleural fistula (Clavien–Dindo grade IIIa): procedure under local anesthesia indicated.
7. Delayed wound healing (Clavien–Dindo grade II): medical management indicated (e.g., antibiotics).
8. Chyle fistula (Clavien–Dindo grade IIIa): image-guided drain placement or paracentesis including drain replacement indicated.
9. Pulmonary embolism (Clavien–Dindo grade IIIa): intervention under general anesthesia indicated (pulmonary artery thrombectomy).

One patient in this study experienced an acute myocardial infarction following the surgery. Unfortunately, despite efforts to resuscitate, the patient did not survive.

Follow-up

All patients received postoperative anti-tuberculosis (ATB) treatment, which included Isoniazid, rifampicin, pyrazinamide, ethambutol for 2 months, followed by Isoniazid and rifampicin for an additional 4 months. After surgery, patients were monitored through outpatient check-ups for a minimum of 6 months. Pulmonary CT scans, sputum smears, and sputum cultures were performed at 1, 3, and 6 month post-surgery. Tuberculosis medication was discontinued after the sixth month, following evaluation of these tests. The follow-up results showed no recurrence of tuberculosis, and no deaths were reported during the follow-up period. Three patients were lost to follow-up due to living out of province after surgery, and data from these three cases have been excluded from the study.

Statistical analyses

Categorical variables are presented as counts and percentages, while continuous variables are expressed as means with standard deviations (SD) or medians with ranges. For variable frequencies, Pearson's chi-squared test was used, and for continuous variables, either the Student's t test or the Wilcoxon rank-sum test was applied, depended on the distribution of the variable. Logistic regression was utilized to identify risk factors for postoperative complications. All analyses were performed with SPSS software (IBM, SPSS Inc., version 24.0). A p value of less than 0.05 was considered statistically.

Results

Patient characteristics (Table 1)

This study enrolled 204 patients diagnosed with PTB who underwent surgery at our hospital between January 2018 and September 2022. Among these, 138 cases (67.6%) were male and the median age was 49 years. The BMI ranged from 17.5 to 26.4 kg/m^2, with a median of 21.9 kg/m^2. Twenty-seven individuals accompanied with diabetes mellitus, and 22 patients had hypertension. According to history review, 122 patients had a previous COVID-19 infection, with 89 being asymptomatic and 33 experiencing mild symptoms. One hundred thirty-two patients were classified as ASA2, while 72 were classified as ASA3. Nineteen patients were heavy smokers, and 58 were moderate smokers. The median of FEV1% was 85.2%. Eighty-six patients presented with hemoptysis before surgery, and only 11 agreed to undergo preoperative bronchial arterial embolization (BAE) treatment. The median duration of anti-tuberculosis treatment prior to surgery was 30 days. Preoperative chest CT scans identified 120 patients with lesions exhibiting mild adhesions to surrounding tissues, while 84 patients had severe adhesions. The maximum diameter of lung lesions ranged from 2 to 20 cm, with a median of 5 cm. Ninety-two patients had lesions in the right lung, and 112 patients had lesions in the left lung. Regarding laboratory tests, the median WBC count was 5.64×10^9/L, the median ESR was 13 mm/H (normal range for male: 0–15 mm/h, and for females: 0–20 mm/h), and the median high-sensitivity C-reactive protein (HCRP) level was 1.75 mg/L (normal level in healthy adults are less than 5 mg/L).

Operative factors (Table 1)

According to the classification of surgical approaches, 148 cases underwent VATS, and 56 cases were treated with OS. The types of surgery performed varied, 21 cases underwent lung segmentectomy, 82 cases had lung lobectomy, 51 cases had wedge resection, 31 cases required complex lobectomy, and 19 cases underwent total pneumonectomy due to the destruction of one lung by tuberculosis. During surgery, 31 cases required blood transfusions due to intraoperative blood loss exceeding 800 mL. The median (range) surgical time for all patients was 210 (25–610) min, reflecting considerable variation in surgery duration depending on the case. Similarly, the amount of bleeding during the surgery varied greatly, the median (range) intraoperative bleed loss was 200 (5–6000) mL.

Postoperative complications (Table 1)

The result showed that 63 patients in this study experienced surgery-related complications, accounting for an incidence rate of 30.9% (63/204). In some cases, patients experienced multiple types of complications simultaneously. The most common complications included PAL (29 cases: Clavien–Dindo grade I in 21, grade II in 5, IIIa in 3), postoperative PE (23 cases: Clavien–Dindo grade I in 17, grade II in 4, IIIa in 2), PRS (27 cases: Clavien–Dindo grade I in 22, grade II in 4, IIIa in 1), pneumonia (9 cases: Clavien–Dindo grade I in 1, grade II in 4, grade IIIa in 2, grade IIIb in 1, grade V in 1) and hemorrhage (5 cases: Clavien–Dindo grade I in 1, grade II in 1, grade IIIa in 1, grade IIIb in 2). Less common complications included postoperative bronchopleural fistula (1 case: Clavien–Dindo grade IIIa), delayed wound healing (1 case: Clavien–Dindo grade II), chyle fistula (1 case: Clavien–Dindo grade IIIa), and pulmonary embolism (1 case: Clavien–Dindo grade IIIa). Unfortunately, the study also reported 2 deaths, resulting in a mortality rate of 0.98%. One patients died due to lung infection, while the other passed away from a myocardial infarction.

Univariate analysis

Table 2 shows the relationship between patient characteristics and postoperative complications. There was no significant difference in previous COVID-19 status between the groups with and without postoperation complications ($p = 0.590$). Postoperative complications were more likely to be associated with male gander ($p = 0.007$), ASA grade 3 ($p = 0.001$), severe adhesion grade ($p = 0.001$), hemoptysis before surgery ($p < 0.05$), lobectomy or combined lobectomy ($p < 0.05$), and the need for blood transfusion during the surgery ($p < 0.05$). The median maximum diameter (IQR) of lesions in patients with postoperative complications was 7 (5–10) cm, which was statistically different ($p < 0.05$) from the median maximum diameter (IQR) of lesions in patients without postoperative complications, which was 5 (3–7) cm. The incidence of complications was higher in patients who underwent lobectomy or combined lobectomy compared to those who underwent sublobe resection. The median operative times (IQR) for patients with complications was 315 (210–380) min, significantly longer than for patients without complications ($p < 0.05$). The median intraoperative blood loss (IQR) in patients with complications was 500 (200–1200) mL, which was higher than in patients without complications ($p < 0.05$). No association was found between the occurrence of postoperative complications and whether the surgery was performed via thoracoscopy ($p > 0.05$).

Table 3 shows the relationship between patient characteristics and postoperative PAL, postoperative PE, and PRS independently. Patients classified as ASA class 3, with higher degree of adhesion, symptoms of hemoptysis, and those undergoing lung lobe or combined lung lobe resection, as well as those who received blood transfusions during surgery had a higher incidence of residual cavity formation after surgery ($p < 0.05$). Patients with PRS were older, had larger lesion diameter, longer surgery times, and higher median intraoperative blood loss compared to those without PRS ($p < 0.05$). Other postoperative complications were not evaluated for risk factors due to their infrequent occurrence. PAL was more likely to be associated with male patients, a higher degree of adhesion, and those who received blood transfusions during surgery ($p < 0.05$). In addition, patients with PAL tend to have larger lesion diameters, longer operative times and more operative bleeding ($p < 0.05$). Another common postoperative complication is postoperative PE, was more frequent in patients with a higher degree of adhesion, symptoms of hemoptysis, those undergo lung lobe or combined lung lobe resections, and those who receive blood transfusions during surgery ($p < 0.05$). Similar to PAL, patients who developed PE tended to presented with larger lesion diameters, longer surgeries and higher intraoperative blood loss ($p < 0.05$). Patients graded as ASA class 3, with a higher degree of adhesion, presented with symptoms of hemoptysis, and undergoing lung lobe or combined lung lobe resection, as well as those who received blood transfusions during surgery were more likely to experience residual cavity formation ($p < 0.05$). Patients with PRS tend to be older, presented with larger lesion diameters, experienced with longer operative times, and presented with higher intraoperative blood loss compared to those without PRS ($p < 0.05$). It is important to be noted that other postoperative complications were not evaluated for risk factors in this study due to their infrequent occurrence.

Multivariate analysis

The multivariate analyses of risk factors for postoperative complications are presented in Fig. 2. Male sex (odds ratio [OR]: 2.322, 95% confidence interval [CI] 1.015–5.313, $p = 0.046$), severe adhesion grade (OR 4.304, 95% CI 1.710–10.830, $p = 0.002$), and longer operative times (OR 1.007, 95% CI 1.003–1.011; $p = 0.001$) were identified as significant risk factors for postoperative complications. The results of the multivariate analyses for postoperative PAL, postoperative PE, and PRS are presented in Fig. 3. Male sex (OR 4.003, 95% CI 1.111–14.421, $p = 0.034$), severe adhesion grade (OR 3.943, 95% CI 1.313–11.839, $p = 0.014$), and longer operative times (OR 1.005, 95% CI 1.001–1.009, $p = 0.016$) were identified as significant risk factors for PAL. Severe adhesion grade (OR 6.078, 95% CI 1.318–28.026, $p = 0.0214$), longer operative times (OR 1.005, 95% CI 1.000–1.010, $p = 0.043$) were identified as significant risk factors for postoperative PE. Blood transfusion (OR 4.493, 95% CI 1.270–15.888, $p = 0.020$) was identified as a significant risk factor for PRS.

Discussion

Most tuberculosis patients are treated with medication, which is an effective and safe option for the majority. However, ~ 5% of patients with pulmonary TB may develop irreversible lung damage, severe hemoptysis, or drug resistance that cannot be addressed with medication alone, necessitating surgical intervention [13–15]. Common postoperative complications of lung surgery include PAL, PE, PRS, chest bleeding, pulmonary infection, chylothorax, bronchopleural fistula, and poor wound healing. A study has shown that approximately one-third of patients with tuberculosis-destroyed lungs experience complications after surgery [16]. In this study, the most common postoperative complications following lung surgery were found to be PAL, postoperative PE and PRS, with a total incidence rate of 30.9%, which is higher than the rates typically reported in current literature [17]. Surgery on patients with PTB proves more

Table 2 Relationship between patient characteristics or operative factors and postoperative complications

Variables	Postoperative complications		*p* value
	Absent **$N=141$**	**Present** **$N=63$**	
Sex			
Male	87 (61.7%)	51 (81.0%)	0.007
Female	54 (38.3%)	12 (19.0%)	
Age, years, median (IQR)	49 (32–57)	47 (34–62)	0.393
BMI, kg/m^2,median (IQR)	21.9 (21.0–22.9)	21.8 (20.8–23.3)	0.867
ASA grade			
2	102 (72.3%)	30 (47.6%)	0.001
3	39 (27.7%)	33 (52.4%)	
Previous COVID-19 status			
Uninfected	60 (42.6%)	22 (34.9%)	0.590
Asymptomatic infections	59 (41.8%)	30 (47.6%)	
Mildly infected	22 (15.6%)	11 (17.5%)	
Smoking (Index)			
Heavy smoker	12 (8.5%)	7 (11.1%)	0.147
Light smoker	94 (66.7%)	33 (52.4%)	
Moderate smoker	35 (24.8%)	23 (36.5%)	
FEV1%, median (IQR)	84.2 (79.75–87.9)	85.8 (80.1–87.6)	0.729
Adhesion grade			
Mild	102 (72.3%)	18 (28.6%)	0.001
Severe	39 (27.7%)	45 (71.4%)	
DB			
Present	18 (12.8%)	9 (14.3%)	0.767
Absent	123 (87.2%)	54 (85.7%)	
HP			
Present	18 (12.8%)	4 (6.3%)	0.262
Absent	123 (87.2%)	59 (93.7%)	
Hemoptysis			
Present	46 (32.6%)	40 (63.5%)	0.001
Absent	95 (67.4%)	23 (36.5%)	
Pre BAE			
Yes	5 (3.5%)	6 (9.5%)	0.081
No	136 (96.5%)	57 (90.5%)	
ATB time, days, median (IQR)	60 (0–240)	0 (0–180)	0.160
Maximum diameter, cm, median (IQR)	5 (3–7)	7 (5–10)	0.001
WBC, $\times 10^9$/L, median (IQR)	5.48 (4.26–7.08)	6.06 (4.65–8.08)	0.085
ESR, mm/h, median (IQR)	12 (6–25.5)	15 (7–30)	0.381
HCRP, mg/L, median (IQR)	1.57 (0.68–6.10)	2.2 (1.21–11.32)	0.116
Location			
R	67 (47.5%)	25 (39.7%)	0.299
L	74 (52.5%)	38 (60.3%)	
Operative approach			
VATS	103 (73.0%)	45 (71.4%)	0.811
OS	38 (27.0%)	18 (28.6%)	
Operative procedure			
Sublobectomy (Seg/wedge)	61 (43.3%)	11 (17.5%)	0.001
Lobectomy (Lob/Lob + Seg/Lob + wedge/Pneumo)	80 (56.7%)	52 (82.5%)	
Operative times, min, median (IQR)	180 (112.5–250)	315 (210–380)	0.001

Table 2 (continued)

Variables	Postoperative complications		*p* value
	Absent **N = 141**	**Present** **N = 63**	
Operative bleeding, ml, median (IQR)	150 (50–350)	500 (200–1200)	0.001
Transfer blood			
Yes	12 (8.5%)	19 (30.2%)	0.001
No	129 (91.5%)	44 (69.8%)	

challenging due to the extensive adhesions between the lung lesions and surrounding tissues, as well as the abundance of blood vessels. As a result, the risk of postoperative complications is higher compared to other conditions, such as lung cancer [18]. Research on lung tumors indicates that male gender, the presence of asthma combined with low lung function, and the type of surgical approach are all risk factors for complications following lung surgery [19]. Recent studies suggest that COVID-19 significantly affects the development, progression, and prognosis of tuberculosis. In this study, we collected data on prior COVID-19 infections among all patients and conducted a comparative analysis based on the presence or absence of postoperative complications. No significant differences were observed. These findings indicate that a history of COVID-19 infection is not a risk factor for postoperative complications in patients with pulmonary tuberculosis. This may be due to the fact that the COVID-19 cases in our cohort were predominantly mild or asymptomatic, resulting in minimal impairment to lung function and structure. Our research reveals that the single-factor analysis shows postoperative complications are more frequently observed in male patients, those with ASA III grade, severe adhesions, hemoptysis, larger lesion size, lobe resection, longer operative times, and those who underwent intraoperative blood transfusion. The multiple-factor analysis suggests that male sex, severe adhesions, and longer operative times are significant risk factors for postoperative complications. These findings are consistent with current research on pulmonary tuberculosis surgery [20–23]. Therefore, we should greater attention should be given to male patients and those with severe adhesions indicated on preoperative CT, as they are at higher risk for postoperative complications. In addition, careful separation of adhesions during surgery should be prioritized to minimize bleeding and avoid intraoperative blood transfusion, thereby reducing postoperative complications. Furthermore, this study suggests that reducing the operative times can also help lower the incidence of postoperative complications.

Lung resection for patients with PTB has traditionally involved lobectomy or pneumonectomy to fully remove the lesion [24]. However, recent studies suggest that sublobar resection can also be an effective treatment option for patients with limited pulmonary tuberculosis lesions, as it helps preserve more lung function [25]. With the advancement in surgical techniques and improved equipment, VATS has become a viable option for treating PTB. The appropriate surgical approach results in less blood loss, shorter operative times, and shorter hospital stays. Our result also support the feasibility of sublobar resection in treating PTB. Recent literature has reported that minimally invasive surgery causes less trauma compared to traditional open chest surgery, leading to lower postoperative complications [26, 27]. In this study, no significant difference in postoperative complications rates was observed between the VATS and OS groups, indicating that the type of surgical approach is not a risk factor for postoperative complications. Furthermore, recent studies suggest that regional BAE preconditioning combined with surgery may shorten operation time, reduce intraoperative bleeding, and alleviate surgical difficulties [28, 29]. However, this study do not specify whether there is a difference in the incidence of postoperative, complications, such as PAL, postoperative PE, and PRS, between patients who undergo preoperative BAE combined with surgery and those who undergo surgery alone. This study showed that preoperative BAE does not reduce the incidence of postoperative complications. The reason for this phenomenon is preoperative BAE only blocks a small number of bleeding vessels and does not affect intraoperative adhesion or lesion size.

PAL lead to various complications, such as pneumonia, delayed recovery, and prolonged hospital stays. Approximately half of all patients experience minor PAL after lung resections. The definition of postoperative PAL remains inconsistent, with various studies suggesting duration ranging from 4 days to over 10 days [30]. The incidence of PAL varies based on factors, such as underlying lung diseases, the extent of pneumonectomy [31], surgical approaches, patient's health status, and surgical skill, with rates ranging from 15 to 18% in current lung resection surgeries [32]. This study showed a PAL rate of 14.2%, which aligns with current reports. We identified

Table 3 Relationship between patient characteristics or operative factors and postoperative air leakage, effusion, and residual spaces

Factors	PAL		p	PE		p	PRS		P
	Absent N = 175	Present N = 29		Absent N = 181	Present N = 23		Absent N = 177	Present N = 27	
Sex									
Male	112 (64.0%)	26 (89.7%)	0.012	119 (65.7%)	19 (82.6%)	0.164	117 (66.1%)	21 (7.8%)	0.227
Female	63 (36.0%)	3 (10.3%)		62 (34.3%)	4 (17.4%)		60 (33.9%)	6 (22.2%)	
Age, years, median (IQR)	49 (32–59)	47 (33–60.5)	0.908	50 (32–59)	40 (32–63)	0.726	49 (32–57)	60 (35–66)	0.022
BMI, kg/m^2,median (IQR)	21.9 (21.0–22.9)	22.3 (20.9–23.3)	0.642	21.9 (21.0–22.9)	21.7 (20.7–23.3)	0.730	21.9 (21.0–22.9)	21.8 (20.4–23.2)	0.437
ASA grade									
2	116 (66.3%)	16 (55.2%)	0.246	119 (65.7%)	13 (56.5%)	0.383	120 (67.8%)	12 (44.4%)	0.018
3	59 (33.7%)	13 (44.8%)		62 (34.3%)	10 (43.5%)		57 (32.2%)	15 (55.6%)	
Previous COVID-19 status									
Uninfected	71 (40.6%)	11 (37.9%)		74 (40.9%)	8 (34.8%)		76 (42.9%)	6 (22.2%)	
Asymptomatic infections	75 (42.9%)	14 (48.3%)	0.848	77 (42.5%)	12 (52.2%)	0.679	75 (42.4%)	14 (51.9%)	0.090
Mildly infected	29 (16.6%)	4 (13.8%)		30 (16.6%)	3 (13.0%)		26 (14.7%)	7 (25.9%)	
Smoking (Index)									
Heavy smoker	16 (9.1%)	3 (10.3%)		17 (9.4%)	2 (8.7%)	0.496	16 (9.0%)	3 (11.2%)	
Light smoker	112 (64.0%)	15 (51.7%)	0.436	115 (63.5%)	12 (52.2%)		115 (65.0%)	12 (44.4%)	0.105
Moderate smoker	47 (26.9%)	11 (37.9%)		49 (27.1%)	9 (39.1%)		46 (26.0%)	12 (44.4%)	
FEV1%, median (IQR)	84.3 (79.7–87.9)	85.8 (80.9–87.7)	0.437	84.3 (79.9–87.9)	86.2 (78.5–87.4)	0.970	85.3 (79.9–87.7)	84.3 (78.5–88.0)	0.729
Adhesion grade									
Mild	111 (63.4%)	9 (31.0%)	0.001	117 (64.6%)	3 (13.0%)	0.000	114 (64.4%)	6 (22.2%)	0.000
Severe	64 (36.6%)	20 (69.0%)		64 (35.4%)	20 (87.0%)		63 (35.6%)	21 (77.8%)	
DB									
Present	25 (14.3%)	2 (6.9%)	0.429	23 (12.7%)	4 (17.4%)	0.766	22 (12.4%)	5 (18.5%)	0.384
Absent	150 (85.7%)	27 (93%)		158 (87.3%)	19 (82.6%)		155 (87.6%)	22 (81.5%)	
HP									
Present	21 (12.0%)	1 (34%)	0.293	21 (11.6%)	1 (4.3%)	0.484	20 (11.3%)	2 (7.4%)	0.784
Absent	154 (88.0%)	28 (96.6%)		160 (88%)	22 (95.7%)		157 (88.7%)	25 (92.6%)	
Hemoptysis									
Present	70 (40.0%)	16 (55.2%)	0.125	70 (38.7%)	16 (69.6%)	0.005	68 (38.4%)	18 (66.7%)	0.006
Absent	105 (60.0%)	13 (44.8%)		111 (61.3%)	7 (30.4%)		109 (61.6%)	9 (33.3%)	
Pre BAE									
Yes	10 (5.7%)	1 (3.4%)	0.955	8 (4.4%)	3 (13.0%)	0.217	7 (4.0%)	4 (14.8%)	0.062
No	165 (94.3%)	28 (96.6%)		173 (95.6%)	20 (87.0%)		170 (96.0%)	23 (85.2%)	
ATB Time, days, median (IQR)	60 (0–210)	0 (0–225)	0.454	60 (0–225)	0 (0–150)	0.189	60 (0–240)	0 (0–120)	0.096
Maximum diameter, cm, median (IQR)	5 (3–8)	7 (5–9)	0.032	5 (3–8)	9 (6–10)	0.001	5 (3–7)	8 (5–10)	0.001
WBC, $\times 10^9$/L, median (IQR)	5.65 (4.36–7.45)	5.47 (4.36–6.91)	0.950	5.58 (4.34–7.13)	6.18 (4.45–8.74)	0.222	5.60 (4.38–7.30)	5.78 (4.34–7.75)	0.946
ESR, mm/h, median (IQR)	13 (6–29)	13 (6–20)	0.706	12 (6–25)	16 (8–33)	0.176	13 (6–26.5)	13 (7–30)	0.593
HCRP, mg/L, median (IQR)	1.71 (076–6.42)	2.64 (0.97–13.86)	0.388	1.69 (0.74–6.76)	2.40 (1.30–11.49)	0.196	1.61 (0.74–6.49)	2.13 (1.30–13.33)	0.130
Location									

Table 3 (continued)

Factors	PAL Absent *N* = 175	PAL Present *N* = 29	*p*	PE Absent *N* = 181	PE Present *N* = 23	*p*	PRS Absent *N* = 177	PRS Present *N* = 27	*P*
R	80 (45.7%)	12 (41.4%)	0.664	82 (45.3%)	10 (43.5%)	0.868	80 (45.2%)	12 (44.4%)	0.942
L	95 (54.3%)	17 (58.6%)		99 (54.7%)	13 (56.5%)		97 (54.8%)	15 (55.6%)	
Operative approach									
VATS	130 (74.3%)	18 (62.1%)	0.172	132 (72.9%)	16 (69.6%)	0.734	125 (70.6%)	23 (85.2%)	0.178
OS	45 (25.7%)	11 (37.9%)		49 (27.1%)	7 (30.4%)		52 (29.4%)	4 (14.8%)	
Operative procedure									
Sublobectomy (Seg/wedge)	65 (37.1%)	7 (24.1%)	0.175	69 (38.1%)	3 (13.0%)	0.032	68 (38.4%)	4 (14.8%)	0.030
Lobectomy (Lob/Lob + Seg/Lob + wedge/Pneumo)	110 (62.9%)	22 (75.9%)		112 (61.9%)	20 (87.0%)		109 (61.6%)	23 (85.2%)	
Operative times, min, median (IQR)	195 (120–275)	345 (227.5–380)	0.001	205 (125–282.5)	345 (250–445)	0.001	200 (120–282.5)	325 (205–395)	0.001
Operative bleeding, ml, median (IQR)	200 (50–500)	450 (250–1100)	0.001	200 (50–450)	750 (400–1300)	0.001	200 (50–400)	1000 (300–1300)	0.001
Transfer blood									
Yes	23 (13.1%)	8 (27.6%)	0.045	22 (12.2%)	9 (39.1%)	0.001	17 (9.6%)	14 (51.9%)	0.001
No	152 (86.9%)	21 (72.4%)		159 (87.8%)	14 (60.9%)		160 (90.4%)	13 (48.1%)	

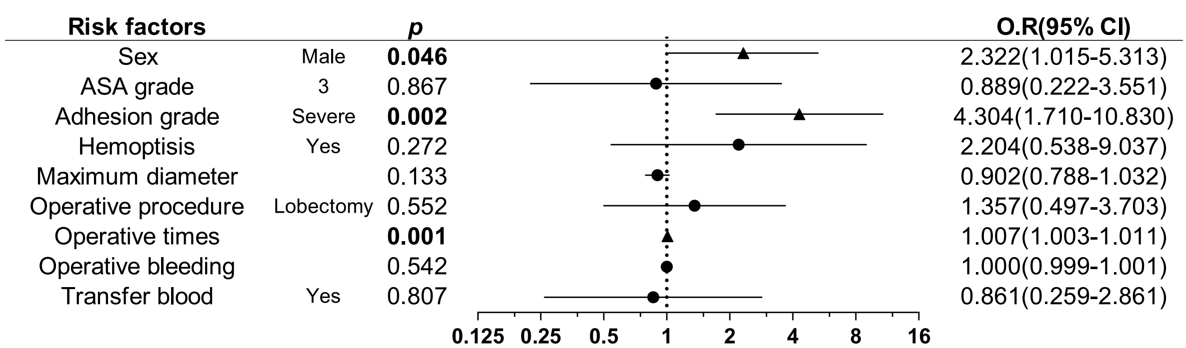

Fig. 2 Multivariate analysis of risk factors for postoperative complications

male sex, severe adhesions, and longer operative times as risk factors for PAL. To prevent PAL, we use various techniques, such as pleural tenting, sealing air leak with talc slurry, prophylactic intraoperative pneumoperitoneum, buttressing staple lines during surgery, and reducing operative times. Several methods can address PAL after surgery, including prolonged chest tube drainage, provocative chest tube clamping, or permissive chest tube removal. Other options include physiotherapy to improve lung function, and the use of agents such as tetracycline, talcum, or silver nitrate for pleurodeses via the chest tube. Some patients may even be managed as outpatients with a chest tube and Heimlich valve [33].

Postoperative PE is defined by the presence of pleural effusion on imaging. On postoperative day 2, 23% of patients experienced a large pleural effusion (> 400 mL/day). Chronic obstructive pulmonary disease, age over 70, and lower lobectomy were found to be independent factors for large PE [34]. Postoperative PE may result from factors, such as large incision, thoracic infection, poor drainage, hypoproteinemia, and heart failure. Treatment includes clinical observation, thoracentesis

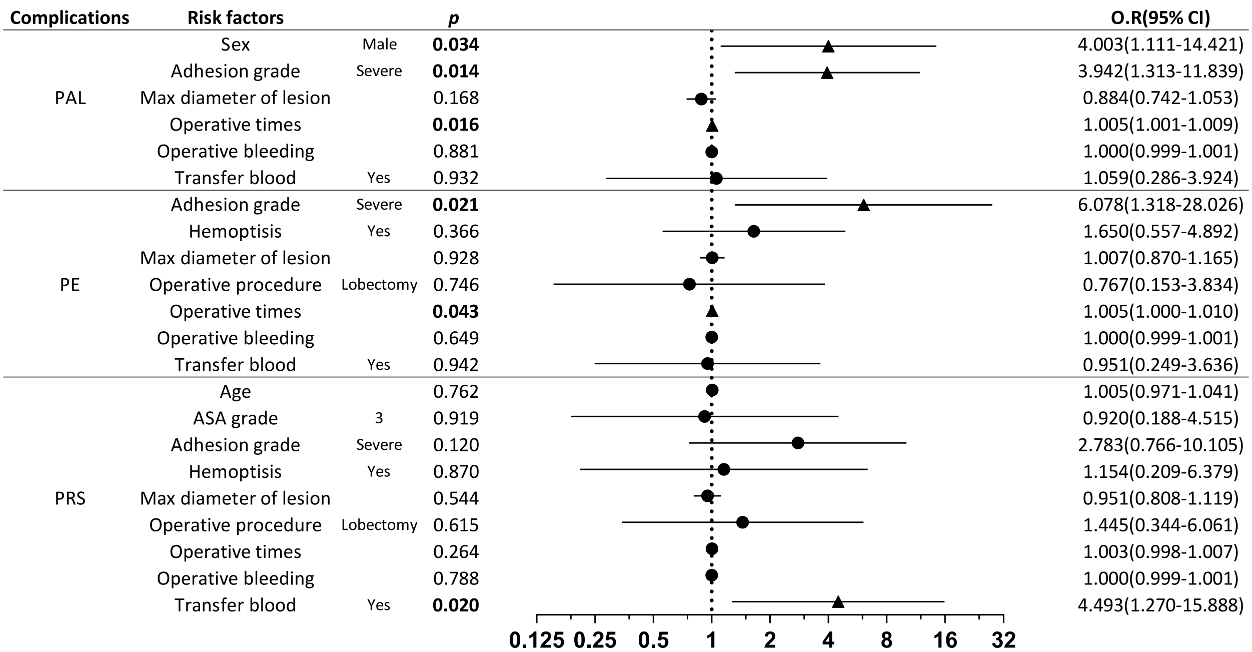

Fig. 3 Multivariate analysis of risk factors for PLA, PE, PRS

drainage, improved protein nutrition, heart function protection, and diuretics. Persistent PE is often observed after lung resection due to imbalances in pleural fluid and reduced lung expansion. Proper chest tube management and postoperative physical therapy can help reduce PE [35, 36]. This study shows that severe adhesions and longer surgical times are risk factors for postoperative PE. Severe adhesion causes greater pleural injury, increasing the risk of pleural effusion, while longer operative times, combined with anesthesia and fluid infusion, may exacerbate pleural edema. Reducing operative time can help mitigate the incidence of postoperative PE.

The incidence rate of postoperative residual pleural space can be as high as 40% in the early days after surgery [37]. PRS is benign and resolves over time, with the residual space typically filled by sterile fluid [38]. In most cases, PRS is benign and resolves over time, with the residual space typically filled by sterile fluid [39]. Physiological changes such as hyperinflation of the remaining lung, mediastinal shift, diaphragmatic elevation, and narrowing of intercostal spaces help eliminate the residual space [40]. This study showed that patients with larger lesions typically undergo more extensive resections, leading to less remaining lung tissue and a higher incidence of PRS. In addition, patients with severe pulmonary adhesions and a fixed pulmonary hilum are more prone to residual cavities. Our multifactorial analysis identified intraoperative transfusion as a risk factor for PRS, likely due to excessive bleeding caused by vascular fragility. To reduce the incidence of PRS, careful preoperative evaluation and avoidance of violent separation during surgery are critical. Techniques such as partial rib resections, transcutaneous phrenic block, and muscle flap transposition can also help reduce PRS.

This article has several limitations. First, it is a single-center retrospective study with a relatively small sample size. Second, although a large amount of clinical data was collected, some data, such as preoperative hemoglobin and albumin levels, were not available. Third, the study lacks an analysis of intraoperative and long-term complications in PTB patients. Multicenter prospective studies are needed to confirm these findings, and further efforts should focus on collecting comprehensive preoperative and postoperative data. Future studies may include the measurement of additional biomarkers or patient-reported outcomes to provide a more detailed understanding of factors impacting surgical complications.

Conclusions

Male gender, severe adhesions, and longer operative times were identified as risk factors for postoperative complications. Specifically, the risk factors for postoperative PAL were male gender, severe adhesions, and longer operative times; for postoperative PE, the risk factors were severe adhesions and longer operative times; and for PRS, intraoperative blood transfusion was the main risk factor. The findings of this study enable us to identify patients at higher risk for postoperative complications prior to surgery, guide intraoperative decision-making, and prompt timely postoperative adjustments in treatment to help reduce the incidence of complications.

Abbreviations

TB	Tuberculosis
PTB	Pulmonary tuberculosis
ATB	Anti-tuberculosis
CT	Computed tomography
VATS	Video-assisted thoracic surgery
OS	Open chest surgery
FEV1%	Forced expiratory volume % in 1 s
BMI	Body mass index
ASA	American society of Aneshesiologists physical status classification system
WBC	White blood cell
ESR	Erythrocyte sedimentation rate
HCRP	High-sensitivity C-reactive protein
BAE	Bronchial arterial embolization
PAL	Prolonged air leak
PE	Pleural effusion
PRS	Postoperative residual pleural spaces
OR	Odds ratio
CI	Confidence interval
SD	Standard deviations
HRZE	Isoniazid, rifampicin, pyrazinamide, ethambutol
HR	Isoniazid, rifampicin
COVID-19	Coronavirus disease 2019

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Author contributions
BW designed the study, collected, analyzed the data and wrote this manuscript. LY, LS, FX, QBL, SB, CG assisted in data collection, XYL, JS, YHJ, XYD supervised and revised the article, and all authors read and certified the article.

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Availability of data and materials
The data of this study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was complied with the Helsinki statement on research ethics and was approved by the Ethics Committee of Wuhan pulmonary Hospital (Approval Number: (2023)01), and written informed consent was obtained from all of the patients.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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