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A pilot study of endobronchial repairment for bronchopleural fistulas

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Abstract

Background Bronchopleural fistulas (BPFs) are severe medical condition with high mortality. When the conventional surgical therapy failed, endobronchial intervention could function as the supplementary option. Several studies reported successful endobronchial managements of BPFs whereas the optimal strategies remain elusive.

Methods We retrospectively reviewed the medical records of patients with BPFs underwent endobronchial interventions with Vaseline gauze, shape-adjustable silicone plug, sutured silicone tube or covered metallic stent in our institution.

Results From 2018 to 2024, a total of 30 patients (11 females VS. 19 males; mean age 48.03 ± 20.33 years) with primary etiology of tumor ($n=19$), empyema ($n=6$), gastro-bronchial fistula ($n=1$), lung infection with immune suppressed status ($n=1$) and spontaneous pneumothorax ($n=3$) were treated. Different occlusive materials were placed including covered metallic stent ($n=6$), shape-adjustable silicone plug ($n=4$), sutured silicone tube ($n=1$) and Vaseline gauze(s) ($n=21$). The dislocation of devices occurred in two patients with covered metallic stent occlusion. On the first day post procedure, 17 patients (56.7%) had complete resolution of the fistulas, compared with 13 patients (43.3%) had incomplete resolution. At the end of the first week post procedure, 19 patients (63.3%) showed complete resolution and 10 patients (33.3%) with partial resolution, whereas one patient (3.3%) failed to have effective closure of the fistula. The representative computer tomography images showed the closure of fistulas and ameliorated hydropneumothorax.

Conclusion Four endobronchial interventional maneuvers, the Vaseline gauze, shape-adjustable silicone plug, sutured silicone tube and covered metallic stent, showed both safe and effective managements for patients with BPFs.

Keywords Bronchopleural fistulas, Bronchial fistulas, Endobronchial intervention, Bronchoscopy, Interventional bronchoscopy

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Introduction

Bronchopleural fistulas (BPFs) are abnormal connections between the pleural space and the bronchial tree, which are most commonly secondary to lung resection procedures (pneumonectomy or lobectomy) [1, 2] with a relative low incidence of 3.2% but high mortality from 25–67% [3, 4], followed by lung infections, chemical or radial complications of malignancy treatment and traumatic injury as fewer common causes [5].

Typical BPFs do not close spontaneously and almost always require certain surgical or endobronchial interventions. Surgical repair is recommended as the curative strategy for post-lung resection BPF > 8 mm [6, 7]. In patients with suppurative pleuropulmonary diseases, advanced malignancy and immunosuppression who are unable to tolerate surgery, bronchoscopic occlusion generally serves as a complementary therapy. Nevertheless, interventional pulmonary specialists commonly select different endobronchial procedures according to the fistula size and clinician expertise. Despite successful attempts to treat BPFs with several modalities of endobronchial occlusion including deployment of airway stents, coils, Amplatzer devices, endobronchial valves, multiple sealing compounds, sclerosants or ablative therapy, there is no consensus on optimal therapy [5, 8].

The purpose of this study is to summarize our experience of BPFs closure with varies devices and materials including Vaseline gauze, shape-adjustable silicone plug, sutured silicone tube or covered metallic stent by analyzing medical records and literature review.

Study design and methods

Patients selection

Retrospectively, patients diagnosed with BPFs who are not suitable for surgical repair underwent endobronchial closure in the Endobronchial Intervention Center of Shanghai East Hospital from May, 2018 to May, 2024 were included. Diagnosis of BPFs were confirmed based on a combination of medical history, clinical manifestation, radiological features, and bronchial endobronchial examinations. Medical records including demographic information, the etiologies of BPFs, comorbidities, size and locations of fistula, manners of occlusion, and updated medical records were collected accordingly. Patients who did not complete postoperative CT reevaluations or had incomplete medical records were excluded. Ultimately, 30 patients were enrolled in this study.

Interventions and comparison

Pre-operative preparations including antibiotics treatment, maintenance of immune and nutritional status, and comprehensive evaluation based on the size and location of fistula, and the anatomic connections with adjacent tissue and/or organs. All patients were intubated with laryngeal mask under general anesthesia in supine position and followed by cardiac and vital signs monitoring during procedure.

Before the bronchoscopy procedure, chest tube was placed for each patient to evaluate the severity of fistula through monitoring air leakage and to facilitate the precise localization of the fistula orifice under the bronchoscope. During the procedure, methylene blue dilution (1 ml concentrate: 50 ml saline) was retrogradely injected through the chest tube and localized through the intrabronchial visualization of the dye. The chest tube was retained several days after procedure to ensure adequate monitoring and stabilization of the patient's condition. Following the successful occlusion of the fistula, the chest tube was subsequently removed prior to discharge.

Four occlusive materials, as shown in Fig. 1, were used in this study. Vaseline gauze is cut into stripes and folded into column (Fig. 1A). Shape-adjustable silicone plug is modified into spindle shape and tied with a suture for clamping by forceps, which is from patented products of our institution (Fig. 1B). Sutured silicone tube is manually sutured at both ends to form a conical plug with closed lumen (Fig. 1C). Covered metallic stent is a self-expandable, custom-built and commercialized product from Micro-Tech Co. Ltd., Nanjing, China. The stent is a dumbbell-like nitinol device covered with polyethylene at both ends to avoid air leaks (Fig. 1D). The occlusive materials were oversized than target airway or fistula to ensure stabilization and airtightness.

For the fistula located distal to subsegmental airway where direct visualization of the orifice via bronchoscopy is challenging, the proximal subsegmental bronchus, according to the methylene blue effusion location, was deemed as culprit bronchus and occluded. For fistula smaller than 3 mm, we chose either Vaseline gauze or shape-adjustable silicone plug for target bronchus obstruction in abovementioned conditions (Fig. 1E, F, I and J). If the fistula is larger than 3 mm but smaller than 10 mm, we opted covered metallic stent for fistula occlusion with proximal portion in bronchus side and distal portion in pleural side and the waist anchoring the orifice of fistula (Fig. 1H and L). For fistula larger than 10 mm, we selected sutured silicone tube for direct occlusion of fistula (Fig. 1G and K).

The deployment of Vaseline gauze, shape-adjustable silicone plug and sutured silicone tube in targeted location is by grasping of forceps through working channel of bronchoscope while the covered metallic stent is deployed with the delivery system. The completion of occlusion was defined as absence of gas drainage from the chest tube. The interventional procedures were mainly performed by flexible bronchoscope (Olympus, Tokyo, Japan) except the placement of sutured silicone tube by rigid bronchoscope (Karl Storz, Tuttlingen, Germany).

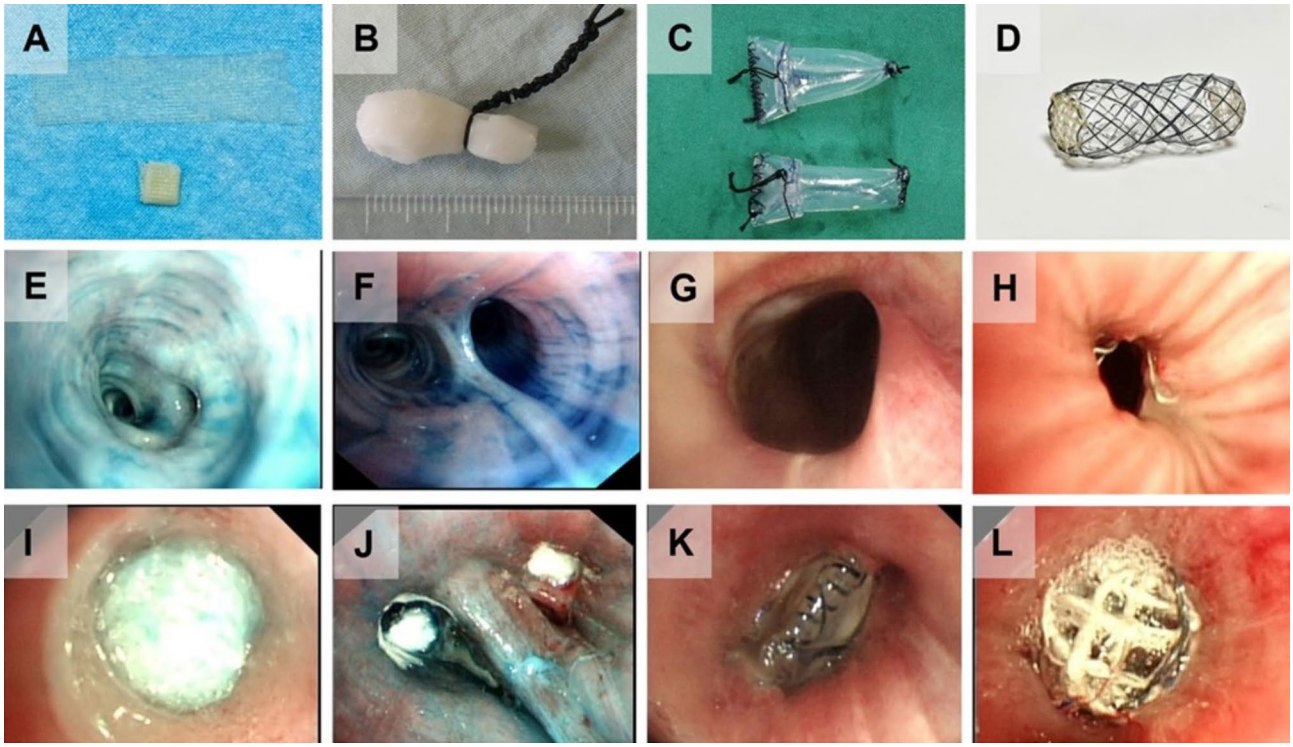

Fig. 1 Occlusive materials and respective endobronchial appearances. (**A**) Vaseline gauze; (**B**) shape-adjustable silicone plug; (**C**) sutured silicone tube; (**D**) covered metallic stent; (**E**) endobronchial view of culprit bronchi before Vaseline gauze occlusion; (**F**) endobronchial view of culprit bronchi before shape-adjustable silicone plug occlusion; (**G**) endobronchial view of fistula before sutured silicone plug occlusion; (**H**) endobronchial view of fistula in surgical stump before covered metallic stent occlusion; (**I**) endobronchial view of culprit bronchi after Vaseline gauze occlusion; (**J**) endobronchial view of culprit bronchi after shape-adjustable silicone plug occlusion; (**K**) endobronchial view of fistula after sutured silicone plug occlusion; (**L**) endobronchial view of fistula in surgical stump after covered metallic stent occlusion

All patients were monitored closely after the procedure for both clinical symptoms (any progressive dyspnea, cough, tachycardia, fever and chest pain) and physical findings (newly onset rales or absent of respiratory sound on auscultation and subcutaneous emphysema). Bedside Chest X-ray on the first day post procedure was performed and chest computed tomography (CT) were performed on the end of first week post procedure to evaluate both the effectiveness of occlusion and potential complications including atelectasis, dislocation of occlusive materials, and infection. Patients underwent a follow-up evaluation one-month post-discharge, including an assessment of clinical symptoms, laboratory findings, and CT imaging to monitor fistula healing progress and detect potential complications. If the clinical and radiological conditions were favorable, bronchoscopy was repeated to remove the occlusive materials. During this procedure, the integrity of the fistula healing was meticulously evaluated under direct endoscopic visualization to ensure complete closure.

Outcomes assessment and data analysis

The primary outcome of this study is the efficacy of transbronchial interventions in the treatment of BPFs. The resolution evaluation was performed on the first day and the end of first week post procedure, and the efficacy was assessed based on clinical symptoms, air leak detection from the chest drainage system, radiological images and/or repeated bronchoscopic features. The primary outcomes are categorized as follows: **Complete resolution** [9]: Closure of the entire related bronchial segments with significant improvements of clinical symptoms including shortness of breath, subcutaneous emphysema and/or no air leakage detected from the closed chest drainage system. Additionally, no complications were observed during the hospital stay. **Partial resolution**: presence of residual fistula lesion, partially relieved symptoms and/or complicated with either atelectasis, infection or dislocation of materials. **Ineffectiveness**: failed closure of the fistula and no symptomatic improvement. Complete and partial resolution were identified as effective. The secondary outcome is the safety of transbronchial interventions for BPFs which was defined as complications occurrences including post-operative atelectasis, dislocation of materials and/or infection.

Ethic approval

This study was conducted in accordance with the amended Declaration of Helsinki. Local independent ethics committees of Shanghai East Hospital approved the protocol, and the Institutional Review Board (IRB) Approval Number is EC.D(BG)0.025.04.0. Written informed consent was obtained from all patients for the off-labeled application of occlusive materials and the information collection of their medical records.

Results

As shown in Tables 1 and 19 males and 11 females with mean age ranging from 15 to 73 years (48.03 ± 20.33 years) were treated in our institution. The primary etiologies for BPF included tumor ($n = 19$), empyema ($n = 6$), gastro-bronchial fistula ($n = 1$), pulmonary infection with immune suppressed status ($n = 1$) and spontaneous pneumothorax ($n = 3$). Eight patients were recorded as status of post lobectomy for malignancy prior to endobronchial intervention. The mean diameter of the fistula is 4.331 ± 2.38 mm except 16 patients with unreportable size. Overall, the occlusive materials were placed in the left upper lobe (LUL) ($n = 10$), left lower lobe (LLL) ($n = 9$), right upper lobe (RUL) ($n = 11$), right middle lobe (RML) ($n = 6$), right lower lobe (RLL) ($n = 12$), intermediate bronchus of right lung ($n = 2$) and right main bronchus ($n = 1$). For each patient, different occlusive materials were placed including covered metallic stent ($n = 6$), shape-adjustable silicone plug ($n = 4$), sutured silicone tube ($n = 1$) and Vaseline gauze(s) ($n = 21$).

The overall effectiveness, as shown in Table 2, was 96.6% (29/30) at the end of the first week post procedure, with 19 patients experienced completed occlusion of their fistula and 10 patients with partial resolution of their condition. Case 1 in whom Vaseline gauze failed to close the fistula was referred for surgical repairment.

Major complications including peri-fistula infection was observed in case 1, case 4 and case 16 and the overall rate is 10%. As shown in Table 3, no atelectasis was detected through clinical symptoms, physical examinations and chest X-ray or CT scan.

In cases 12 and 14, covered metallic stents were deployed as the initial intervention to occlude BPFs. Within the first 3 days post-procedure, however, potential displacement of the stents was identified based on clinical symptoms and chest tube drainage observation. Consequently, bronchoscopy procedures were repeated, during which the position adjustment of the stent was performed transbronchially instead of a second placement. One-month follow-up evaluations revealed effective occlusion in both patients, as evidenced by symptomatic improvement and CT scan image. For patients with partial resolution outcomes, the most common symptom after the procedure is cough, potentially induced by the implantation of foreign material, which was observed 100% both on the first day and one week post procedure. Sputum production was present in 7 out of 10 patients with PR upon the first week evaluation, parallel with 3 patients of residual subcutaneous emphysema a(patient 8, 20 and 29). In case 16, left main bronchus was selected for the closure procedure with Vaseline gauze on account of multiple fistulas and limited pulmonary function after lobectomy. A L-shaped metallic stent bypassing the carina was inserted temporarily to prevent the migration of gauze that might potentially leads to trachea obstruction. In case 17, before the occlusion procedure, we performed argon plasma coagulation to facilitate with the fistula closure but unfortunately failed due to the penetration through the bronchus wall.

Representative comparison of Chest CT scan is listed as Fig. 2. Figure 2A demonstrates patient 4 with a history of thymoma and chronic HBV infection who had fistulas in medial segment of right middle lobe and superior segment of right lower lobe. The pleural effusion remained despite the drainage of chest tube (Fig. 2A) and reduced after the occlusion of target bronchus by Vaseline gauze (Fig. 2E). Figure 2B presents a fistula located in anterior and apical segments of right upper lobe with spontaneous pneumothorax (patient 9). The updated CT scans in the following 12 weeks after bronchoscopic intervention exhibited resolution of the gas and fluid and re-expansion of compressed lung (Fig. 2F). Figure 2C exhibits trapped air in chest of patient 13 who received lobectomy for pulmonary squamous cell carcinoma. After the obstruction of 10.8 mm fistula in middle segment of right middle lung by sutured silicone tube, the cavity shrunk (Fig. 2G). The comparison between Fig. 2D and H elucidates that the dehiscence of surgical stump in left lower lobe due to post-operational empyema was closed persistently after removal of covered metallic stent (patient 14).

We summarized the outcomes of patient follow-up one month after discharge, along with the status of occlusive materials, as detailed in Supplement Table 1. Due to the relative ease of removal during bronchoscopy procedures, Vaseline gauze was successfully retrieved from 18 patients (85.7%) following adequate fistula healing. Conversely, the other three occlusive materials were left in place. In cases 24 and 28, notably, Vaseline gauze was initially placed but failed to occlude the fistula thus covered metallic stents were deployed in the intermediate bronchus instead. As a result, removal of stents was not performed due to the relatively large, challenging-to-heal fistulas.

Discussion

In this retrospective study, we reported a series of 30 patients with BPFs successfully managed by four innovative endobronchial maneuvers. The management of

Table 1 Demographics and clinical features of patients

No.	Age	Gender	Diagnosis	Comorbidities	Fistula Location	Suspected Fistula Size[a]	Occlusion Materials
1	34	F	Gastro-bronchial fistula	N/A	Lateral basal segment of LLL	3.4mm	Vaseline gauze
2	16	M	Osteosarcoma with pulmonary metastasis	N/A	Superior, medial basal and posterior basal segment of RLL	N/A	Vaseline gauze
3	21	M	Osteosarcoma with pulmonary metastasis	N/A	Superior segment of LLL	3mm	Vaseline gauze
4	57	F	Thymoma	Chronic Hepatitis B Virus infection	Medial segment of RML and superior segment of RLL	N/A	Vaseline gauze
5	40	F	Thymoma	Thyroid cancer	LUL	4.5mm	Vaseline gauze
6	37	F	Thymoma	N/A	Anterior, superior, and posterior basal segments of LLL	N/A	Vaseline gauze
7	73	M	Pulmonary adenocarcinoma	Hypertension	Apical and anterior segments of RUL	N/A	Vaseline gauze
8	23	M	Pulmonary infection	AIDS; Talaromyces Marneffei, Burkholderia and Legionella	Medial and lateral basal segments of RLL	N/A	Shape-adjustable silicone plug
9	18	M	Spontaneous pneumothorax	N/A	Anterior and apical segments of RUL	N/A	Shape-adjustable silicone plug
10	67	M	Empyema	N/A	Apical and posterior segments of LUL	N/A	Shape-adjustable silicone plug
11	21	M	Empyema	N/A	Anterior basal segment of LLL	N/A	Shape-adjustable silicone plug
12	70	F	Pulmonary adenocarcinoma	Hypertension	RUL	4.5mm	Covered metallic stent
13	61	M	Pulmonary squamous cell carcinoma	N/A	Middle segment of RML	10.8mm	Sutured silicone tube
14	22	F	Empyema	N/A	Surgical stump of LLL	5mm	Covered metallic stent
15	58	M	Pulmonary squamous cell carcinoma	Type 2 diabetes mellitus	RML	9mm	Covered metallic stent
16	53	F	Mesothelioma	Thyroid nodule hysteromyoma	Surgical stump of LLL, apical-posterior segment, superior and posterior lingual segment of LUL	N/A	Vaseline gauze
17	15	M	Osteosarcoma with pulmonary metastasis	N/A	Superior and basal segments of RLL	N/A	Vaseline gauze
18	74	M	Pulmonary infection	COPD	Anterior segment of RUL	4mm	Vaseline gauze
19	72	M	Pneumothorax	COPD	Anterior segment of RUL	2mm	Vaseline gauze
20	58	M	Empyema	Diabetes	Inferior lingual segment of LUL	3mm	Vaseline gauze
21	30	F	Thymoma	Good's syndrome	Posterior basal segment of LLL	5mm	Vaseline gauze
22	70	M	Empyema	N/A	Posterior and apical segment of LUL	N/A	Vaseline gauze
23	52	M	Lung adenocarcinoma	N/A	Posterior, apical and anterior segments of RUL	N/A	Vaseline gauze
24	72	M	Lung squamous cell carcinoma	N/A	Superior segment of RLL Intermediate bronchus of right lung	3mm N/A	Vaseline gauze Covered metallic stent
25	58	F	Bronchobiliary fistula	Cholangiocarcinoma	Lateral segment of RML	3.3mm	Vaseline gauze
26	64	F	Lung adenocarcinoma	N/A	Lingula lobe of left lung	2.5mm	Vaseline gauze
27	46	F	Empyema	N/A	Superior and basal segments of RLL	2.3mm 4mm	Vaseline gauze
28	66	M	Empyema, post resection of the right lung	Bronchiectasis	RML Intermediate bronchus of right lung	N/A	Vaseline gauze Covered metallic stent

Table 1 (continued)

No.	Age	Gender	Diagnosis	Comorbidities	Fistula Location	Suspected Fistula Size[a]	Occlusion Materials
29	21	M	Empyema Pulmonary metastasis of osteosarcoma	Osteosarcoma	Superior segment of RLL Anterior segment of RUL Lateral segment of RML	N/A	Vaseline gauze
30	63	M	Adenocarcinoma	N/A	Right main bronchus	N/A	Covered metallic stent

NA, not available; LLL, left lower lobe; RLL, right lower lobe; RML, right middle lobe; LUL, left upper lobe; RUL, right upper lobe; AIDS, Acquired Immune Deficiency Syndrome

[a] Some data is not available because the fistula is either too small to measure on CT scan or unable to be observed under bronchoscopy

Table 2 Post-operative assessments for endobronchial intervention of BPFs

Assessment	1 day	1 week
Complete Resolution	15	19
Partial Resolution	14	10
Ineffectiveness	1	1
Atelectasis	0	0
Dislocation of occlusive materials	2	0
Infection	0	3

BPFs remains challenging to both thoracic surgeons and pulmonologists due to the high risk of infection after the traditional open-window thoracostomy. Moreover, the majority of BPFs are secondary as a complication of lung resection procedures, which limited the applications of surgical interventions. On the other hand, significant pleural contamination, scarring, mechanical ventilation, poor immune and nutritional status resulting in the inferiority of surgical repairment. By contrast, endobronchial procedure is regarded more suitable with advantages such as smaller lesion and a relative short-term recovery for patients with contraindications of surgery.

Regarding the bronchoscopic therapeutic strategies, individual selection should be considered according to not only the fistular size, location and underlying comorbidities, but also the material characteristics of the occluders. We proposed that when fistula is smaller than 3 mm or locates proximally to subsegmental bronchus, Vaseline gauze and shape-adjustable silicone plug are recommended for culprit bronchus occlusion. These two devices can be rapidly adjusted into appropriate shape fitting individual lesions during the bronchoscopy which might be affordable for low-income patients and time-saving for physically unstable patients. In addition, argon plasma coagulation is not recommended as the therapy of BPFs smaller than 3 mm, contradicts opinions of Aynaci E et al. [10], for the possibility of fistula expansion that usually requires reoperation.

In patients with fistula larger than 3 mm but smaller than 10 mm, the covered metallic stent is suggested whereas sutured silicone tube is applied when fistula is larger than 10 mm. Lin et al. [11] reported a successful treatment of postpneumonectomy patient with a 4 mm BPF in the right main bronchus with dumbbell-shaped covered metallic stent. Conversely, our experience illustrated the limitation of the utilization of covered metallic stent, because of the smoothing property and migration tendency while coughing and the risk causing asphyxia when dislodgement happened, for fistulas located in the main bronchus.

Furthermore, this study offers evidence to extend the indication of bronchoscopic treatment in BPFs patients. It is widely recognized that surgery repair is recommended for fistulas larger than 8 mm, while currently, several investigators reported successful attempts of customized silicone [12, 13] or covered metallic Y- or L-shaped stents in closure of BPFs in bronchial stumps regardless of the fistula size [14, 15]. Similarly, the Amplatzer devices are reported applicable to close BPFs with a variety of diameters [16]. Bai et al. managed three patients with BPFs larger than 8 mm via Amplatzer vascular plug and reported complete closure in all patients (100%) [17]. In this series, two cases supported the application of flexible bronchoscopy for fistulas larger than 8 mm without significant adverse effects.

Additionally, for better prognosis, it is vital to take precautions against pulmonary infection after the endobronchial intervention. In the study by Travaline et al. [9], the infection rate subsequent to endobronchial treatment of persistent air leaks was reported 5% (two of 40 patients) with colonization of methicillin-resistant Staphylococcus aureus in one patient. It is reported that pneumonia caused the demise of 10% and 8% of patients following the endobronchial occlusion of BPFs with the Amplatzer device and Amplatzer vascular plug respectively [16]. The causes impede the successful closure in case 1 were attributed to the reinfection of fistula and chemical erosion by gastric acid. Accordingly, fistula with excessive mucus secretion or coexisting with bronchiectasis are vulnerable to infection whereas the integrity of surrounding parenchyma and effective anatomical drainage

Table 3 Efficacy and safety evaluation of patients

No.	1 day post-procedure			1 week post-procedure		
	Efficacy	**Symptoms**	**Complications**	**Efficacy**	**Symptoms**	**Complications**
1	Ineffectiveness	Cough with sputum Shortness of breath Air leakage	Infection	Ineffectiveness	Cough with sputum Shortness of breath Air leakage	Infection
2	CR	/	/	CR	/	/
3	CR	/	/	CR	/	/
4	PR	Cough with sputum	Infection	PR	Cough with sputum	Infection
5	CR	/	/	CR	/	/
6	CR	/	/	CR	/	/
7	PR	Cough	/	PR	Cough	/
8	PR	Cough Residual subcutaneous emphysema	/	PR	Cough Residual subcutaneous emphysema	/
9	CR	/	/	CR	/	/
10	PR	Cough with sputum	/	CR	/	/
11	PR	Cough with sputum	/	CR	/	/
12	PR	Cough with sputum	Dislocation	CR	/	/
13	CR	/	/	CR	/	/
14	PR	Cough with sputum	Dislocation	CR	Cough with sputum	/
15	CR	/	/	CR	/	/
16	PR	Cough with sputum	Infection	PR	Cough with sputum	Infection
17	PR	Cough	/	PR	Cough	/
18	CR	/	/	CR	/	/
19	CR	/	/	CR	/	/
20	PR	Cough with sputum Residual subcutaneous emphysema	/	PR	Cough with sputum Residual subcutaneous emphysema	/
21	PR	Cough with sputum	/	PR	Cough with sputum	/
22	PR	Cough with sputum	/	PR	Cough with sputum	/
23	CR	/	/	CR	/	/
24	CR	/	/	CR	/	/
25	PR	Cough with sputum	/	PR	Cough with sputum	/
26	CR	/	/	CR	/	/
27	CR	/	/	CR	/	/
28	CR	/	/	CR	/	/
29	PR	Cough with sputum Residual subcutaneous emphysema	/	PR	Cough Residual subcutaneous emphysema	/
30	CR	/	/	CR	/	/

through airway ensure a better resolution of BPFs when occluded by Vaseline gauze.

The limitation of this study is that it is retrospective and descriptive. Further prospective and controlled studies with larger samples are warranted to determine the value of different interventions that facilitate the formulation of BPFs treating protocol.

In conclusion, endobronchial intervention using four occlusive materials is a minimal-invasive, prompt and cost-effective therapy for BPFs which can be applied to both non-surgical and surgical candidates. Comprehensive strategies based on the fistular size and location, concurrent comorbidities, and the characteristics of the occlusive materials should be obtained for the individualized formulation for patients with BPFs.

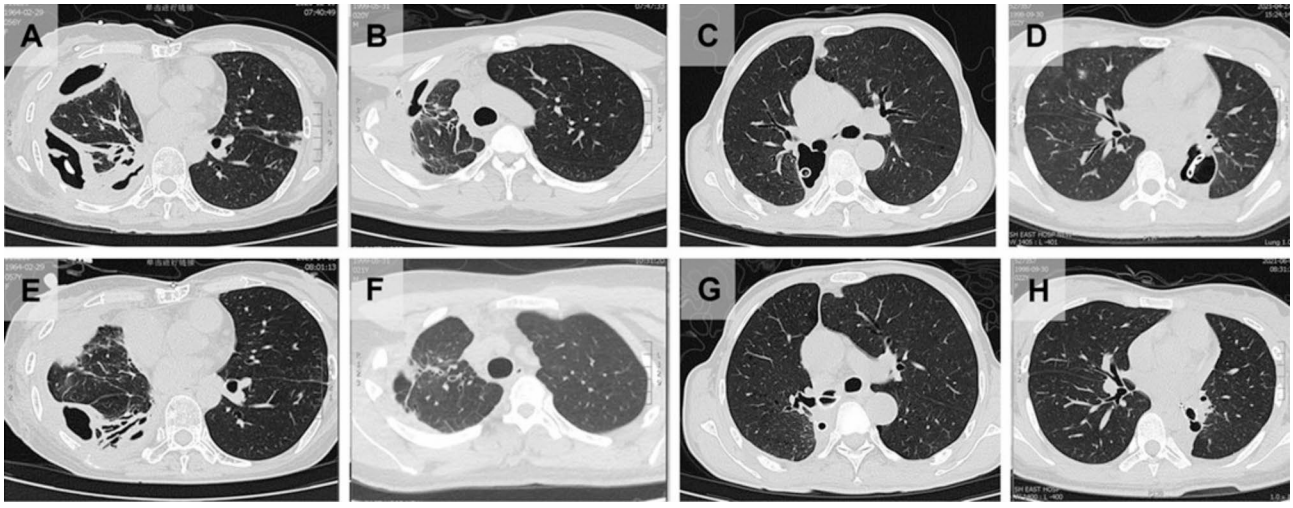

Fig. 2 The comparison of representative CT scans before and after culprit bronchi occlusion. The upper and lower rows are CT scans before (**A**–**D**) and after (**E**–**H**) treatment respectively. The column from left to right, is the CT scan of patients using Vaseline gauze (case 4, A, E), shape-adjustable silicone plug (case 9, B, F), sutured silicone tube (case 13, C, G) and covered metallic stent (case 14, D, H)

Abbreviations

BPFs	Bronchopleural fistulas
CT	Computed tomography
LLL	Left lower lobe
LUL	Left upper lobe
NA	Not applicable
RLL	Right lower lobe
RML	Right middle lob
RUL	Right upper lobe

Supplementary Information

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Supplementary Material 1

Acknowledgements
Not applicable.

Author contributions
Z. L. and Q. L. designed the occlusive materials and conducted the endobronchial interventions. Z. L. and N. W. conceptualized the study. T. L., C. C. and D. L. acquired the data. Z. L., Y. Z. and Y. M. interpretated the results. Y. Z. and G. Y. reviewed the literatures, wrote the original draft and drafted the figures. N. W. wrote the original draft and revised the final manuscript. All authors have reviewed and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This study was conducted in accordance with the amended Declaration of Helsinki. Local independent ethics committees of the local hospital approved the protocol, and the Approval Number is EC.D(BG)025.04.0. Written informed consent was obtained from all patients for the off-labeled application of occlusive materials.

Consent for publication
Not applicable.

Clinical trial number
Not applicable.

Competing interests
Qiang Li has a patent application granted related to shape-adjustable silicone plug which is one of the occlusive materials utilized in this study. All other authors have no financial disclosures and affirm that the research, analysis, and conclusions presented in this article were conducted objectively and without influence from the pending patent application.

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