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Bronchoscopic placement of custom-made sutured silicone prostheses for refractory tracheal hemoptysis: a retrospective case series

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Research Article

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Abstract

Background

Refractory tracheal hemoptysis remains difficult to control when conventional hemostatic medication and bronchial artery embolization fail. This study explored the clinical efficacy and safety of bronchoscopic placement of custom-made sutured silicone prostheses as a minimally invasive salvage option.

Methods

A total of 4 patients with refractory tracheal hemoptysis who did not respond to hemostatic medications and arterial embolization were retrospectively enrolled. The underlying causes included lung cancer cavity, aortic malformation complicated with tracheal fistula, and diaphragmatic arterial tracheal fistula. Preoperative enhanced chest CT was performed to accurately localize the bleeding segmental bronchus. Under general anesthesia, rigid or flexible bronchoscopy was applied for intraoperative exploration. Conical artificial occlusive prostheses were individually tailored and sutured with medical silicone materials, then precisely implanted via bronchoscopy to occlude the bleeding bronchus. All patients received standardized antitussive treatment postoperatively and were followed up for 12 months. The hemostatic effect, pulmonary function tolerance and incidence of complications were evaluated.

Results

All 4 patients underwent successful operation without severe airway injury during the procedure. Hemoptysis was completely resolved within 24 to 36 hours after prosthesis placement. No recurrence of hemoptysis was observed during the 3-, 6- and 12-month follow-up periods. Only one patient developed low-grade fever (peak temperature 38.1°C) within 24 hours after surgery, which was relieved after symptomatic management. No prosthesis displacement, airway obstruction, aggravated infection or other severe complications occurred. The ventilatory function of all patients was basically unaffected, and their quality of life was significantly improved.

Conclusions

Bronchoscopic placement of custom-made sutured silicone prostheses yielded reliable immediate hemostasis, no recurrence during 12-month follow-up and a favorable safety profile in this small retrospective case series. This technique may serve as a salvage therapy for selected patients with refractory tracheal hemoptysis after failure of medication and arterial embolization.

Clinical trial number: not applicable.

Background

Hemoptysis is one of the most common acute diseases in the fields of respiratory medicine and interventional pulmonology. It refers to a clinical syndrome characterized by bleeding from the respiratory tract or lung tissues below the larynx that is expectorated through the oral cavity [1]. The etiology of hemoptysis is complicated, including bronchiectasis, pulmonary tuberculosis, malignant lung tumors, airway-vascular malformations, lung abscess and dozens of other disorders. It accounts for 10% to 15% of emergency visits in respiratory departments of primary hospitals in China. Massive hemoptysis, defined as expectorated blood volume ≥ 500

mL within 24 hours or a single hemoptysis volume ≥ 100 mL, has a mortality rate of 7% to 30%, which is a critical illness seriously endangering patients' lives [2]. Refractory hemoptysis is defined as severe hemoptysis that cannot be effectively controlled or relapses shortly after standardized hemostatic medication and bronchial artery embolization (BAE), and patients are ineligible for or intolerant to surgical resection. It remains a major challenge in the management of critical respiratory diseases [3].

Currently, the therapeutic regimens for refractory hemoptysis have obvious limitations. Vasoactive drugs such as pituitrin and somatostatin are basic hemostatic agents in clinical practice. However, they are only effective for partial bronchial artery-derived bleeding, with limited efficacy against non-bronchial arterial hemorrhage, tumor-related bleeding and bleeding caused by vascular malformations. In addition, these drugs exert obvious cardiovascular adverse reactions and are contraindicated in patients with hypertension, coronary heart disease and arrhythmia, which restricts their application in critically ill patients [4, 5]. As a first-line interventional therapy for massive hemoptysis, BAE achieves a short-term hemostatic rate of 70% to 90%. Nevertheless, it has prominent technical defects. For bleeding derived from systemic circulatory branches such as the aorta, intercostal artery and diaphragmatic artery, BAE fails to perform accurate embolization with a high treatment failure rate [6]. Moreover, the vascular recanalization rate after BAE ranges from 10% to 20%, which easily leads to recurrent hemoptysis. Severe complications such as ectopic embolism and spinal cord injury may also occur during the procedure [7, 8]. Pulmonary lobectomy or segmentectomy is a radical treatment for intractable hemoptysis, yet it is associated with large surgical trauma and a high incidence of perioperative complications. Patients with severely impaired pulmonary function, multiple underlying diseases or advanced malignant tumors are generally unable to tolerate surgical trauma, resulting in a narrow scope of clinical application [9, 10].

With the rapid development of interventional pulmonology, bronchoscopy-based minimally invasive therapy has become an important direction for the treatment of refractory hemoptysis. The combined application of flexible and rigid bronchoscopes enables accurate detection and minimally invasive intervention on airway bleeding lesions [11, 12]. Commonly used bronchoscopic hemostatic techniques include electrocoagulation, laser therapy, cryotherapy, argon plasma coagulation and balloon tamponade. Among them, balloon tamponade is the most widely used temporary hemostatic method, which can block the blood flow of bleeding bronchi to achieve rapid hemostasis. However, it can only provide temporary occlusion rather than radical treatment. Long-term indwelling of balloons may cause airway mucosal injury and secondary infection, which cannot meet the long-term treatment demands of refractory hemoptysis [13]. Against this background, endobronchial artificial prosthesis implantation has been gradually applied for refractory hemoptysis. This technique uses customized prostheses to permanently occlude bleeding segmental bronchi, exerting both immediate hemostatic and long-term anti-recurrence effects, and has become a cutting-edge minimally invasive strategy for refractory hemoptysis [14, 15].

At present, endobronchial artificial prostheses are mainly applied in the treatment of airway stenosis, tracheoesophageal fistula and bronchopleural fistula. Mature techniques for customizing and implanting silicone and polytetrafluoroethylene prostheses have been established [16, 17]. The hemostatic mechanism of bronchoscopic placement of sutured artificial prosthesis relies on the combined effect of physical isolation and local hemodynamic regulation. The individually tailored conical silicone prosthesis can closely fit the wall of target bronchi, directly isolate bleeding lesions from the central airway and reduce the impact of blood flow on wounds. Meanwhile, local blood stasis is induced to accelerate platelet aggregation and thrombus formation, realizing immediate hemostasis [18]. The sutures on the prosthesis increase surface friction, preventing

prosthesis displacement and ensuring long-term occlusion efficacy [19]. Compared with medications, BAE and temporary balloon tamponade, this technique has a wide range of indications and is effective for hemoptysis caused by lung cancer cavities and vascular fistulas, including non-bronchial arterial bleeding. It is a minimally invasive procedure with mild trauma; only a small number of patients develop transient low-grade fever, without airway obstruction or severe infection. The raw materials are easy to obtain and can be trimmed and shaped on site, with simple operational procedures. This approach yields a low long-term recurrence rate and significantly improves patients' quality of life, serving as an ideal remedial therapy for refractory hemoptysis [20]. Nevertheless, the clinical application of artificial prostheses for refractory hemoptysis is still in the initial stage. There are no systematic clinical studies or standardized technical specifications, and relevant research data on the efficacy and safety of individually trimmed and sutured conical occlusive prostheses for bleeding bronchi are still lacking.

Based on previous clinical experience, our research team innovatively adopted custom-made conical silicone prostheses through individualized cutting and suture shaping for patients with refractory tracheal hemoptysis who failed conventional treatments including medications and BAE. The prostheses were implanted under bronchoscopic guidance for occlusive hemostasis. This study aimed to systematically explore the clinical efficacy and safety of bronchoscopic placement of sutured artificial prostheses, so as to provide a novel minimally invasive, efficient and safe therapeutic option for critically ill patients with refractory hemoptysis unresponsive to conventional treatments.

Methods

Study Subjects

A total of 4 patients with refractory tracheal hemoptysis admitted in 2024 were retrospectively enrolled in this study.

Inclusion criteria

Patients diagnosed with refractory tracheal hemoptysis, whose symptoms could not be controlled after standardized hemostatic medications and bronchial artery embolization (BAE); The bleeding sites were confirmed by chest imaging and bronchoscopy, with etiologies including lung cancer cavity, aortic malformation combined with tracheal fistula, and diaphragmatic arterial tracheal fistula; The general physical condition of patients was tolerable to bronchoscopic intervention, without absolute contraindications to general anesthesia and endoscopic surgery; Complete clinical data, imaging results and surgical records were available; all patients and their families were fully informed and signed informed consent for interventional treatment.

Exclusion criteria

Patients complicated with severe cardiac, hepatic or renal failure, as well as severe coagulation disorders who could not tolerate interventional procedures; Patients with severe airway stenosis or malformation that prevented the placement of occlusive prosthesis; Patients with active severe pulmonary infection or respiratory failure requiring mechanical ventilation; Cases with incomplete data or lost to follow-up.

Preoperative Evaluation and Preparation

Routine examinations including blood routine test, coagulation function and electrocardiogram were performed in all patients before surgery. Enhanced chest CT combined with three-dimensional airway reconstruction was applied to accurately locate the segmental bronchus of bleeding, measure bronchial diameter and observe airway course. The anatomical relationship between lesions and adjacent blood vessels was evaluated to rule out high-risk surgical areas. Meanwhile, the overall condition of patients was assessed comprehensively according to hemoptysis volume, attack frequency and clinical manifestations.

All patients were instructed to fast for 8 hours and refrain from drinking water for 2 hours before surgery. General anesthesia was adopted for all procedures. A 14 mm×330 mm rigid bronchoscope (Dunbo) or laryngeal mask combined with flexible bronchoscope was used to establish the operative access. Vital signs including heart rate and blood oxygen saturation were monitored throughout the operation, and an anesthesia ventilator was used to maintain stable ventilation during the whole process.

Fabrication of Artificial Prosthesis

Medical silicone facial prosthesis (Model K804ovs-5, Taiyang Medical Device Co., Ltd.) was used as the raw material. According to the bronchial diameter predicted by preoperative CT and bronchoscopy, the materials were tailored into conical occlusive prostheses on site. Ethicon PROLENE 2 − 0 polypropylene non-absorbable sutures were applied for shaping and suture fixation. Sutures were wrapped around the middle part of the prosthesis to increase friction between the prosthesis and airway wall and enhance stability. A traction loop was sewn at the tail of the prosthesis to facilitate grasping, placement and optional removal under endoscopy. The size of each prosthesis was matched to the anatomical characteristics of target bronchus to ensure tight occlusion.

Surgical Procedures

The Olympus BF1T-290 flexible bronchoscope (outer diameter: 5.9 mm, working channel inner diameter ≥ 2.8 mm) was used for the operation. The detailed procedures were as follows:

Endoscopic exploration: The flexible bronchoscope was inserted via rigid bronchoscope or laryngeal mask. Intraluminal blood and clots were thoroughly aspirated, and the airway was irrigated repeatedly with normal saline to identify the opening of bleeding bronchus.

Size verification: The tip of bronchoscope was aligned with the bronchial opening to recheck the matching degree between prosthesis and airway diameter.

Prosthesis placement: Biopsy forceps were delivered through the working channel to grasp the traction loop at the prosthesis tail. The bronchoscope was manipulated to deliver the prosthesis into the bleeding segmental bronchus, and gentle compression was applied to make the prosthesis tightly embedded for complete occlusion.

Effect confirmation: The bronchoscope was retained for several minutes for observation. After confirming no active bleeding or prosthesis displacement, all instruments and bronchoscope were withdrawn stepwise to complete the operation.

Postoperative Management and Follow-up

Antitussive drugs were routinely administered within 72 hours after operation. Patients were strictly instructed to avoid severe cough and straining to reduce the risk of prosthesis shedding. The patient's body temperature, cough, hemoptysis and chest distress were observed immediately, 24 hours and 48 hours after surgery. Regular follow-up was conducted at 3 months, 6 months and 12 months postoperatively. Chest CT was reexamined to observe the position of prosthesis, airway morphology, secondary infection and pulmonary atelectasis. The ventilatory function and daily activity ability of patients were evaluated, and the incidence of complications such as recurrent hemoptysis, prosthesis displacement and airway obstruction was recorded.

Observation Indicators

Primary Observation Indicators

Immediate hemostatic effect: The primary immediate outcome was defined as the time interval from the completion of artificial prosthesis implantation to the complete cessation of hemoptysis. Real-time clinical observation was conducted throughout the perioperative period to record the exact time when gross hemoptysis, bloody sputum and visible airway bleeding disappeared completely. The immediate hemostatic success rate was calculated, with complete cessation of hemoptysis within 72 hours after prosthesis implantation regarded as effective immediate hemostasis.

Long-term therapeutic efficacy: Regular follow-up was performed at 3 months, 6 months and 12 months postoperatively. We recorded the number of patients with recurrent hemoptysis at each time point, and calculated the corresponding hemoptysis recurrence rate. Hemoptysis recurrence was defined as the reappearance of gross bloody sputum or overt airway bleeding after complete hemostasis. The long-term hemostatic effect was comprehensively evaluated according to the recurrence data across different follow-up time points.

Secondary Observation Indicators

Intraoperative safety indicators: Intraoperative vital signs and surgical conditions were continuously monitored. We documented all adverse events occurring during bronchoscopic exploration and prosthesis placement, including airway mucosal laceration, massive intraoperative hemorrhage, severe hypoxemia, respiratory depression, circulatory instability and other procedure-related adverse reactions. The incidence of intraoperative adverse events was statistically analyzed to assess the overall intraoperative safety.

Postoperative complications: Postoperative vital signs, respiratory symptoms and physical signs were dynamically observed. Monitored complications included postoperative fever (recorded the maximum body temperature, duration of fever and treatment measures), prosthesis displacement or shedding confirmed by imaging and endoscopy, airway stenosis and obstruction, secondary bacterial or fungal pulmonary infection,

pneumothorax, pulmonary atelectasis and pulmonary abscess. The type, number and incidence of all postoperative complications were recorded and summarized.

Overall patient tolerance: Patient tolerance was assessed comprehensively combining subjective feelings, clinical signs and imaging examinations. Subjective evaluation focused on symptoms such as persistent cough, chest distress, dyspnea and fatigue. Objective evaluation relied on postoperative chest CT results to observe the morphological changes of target bronchus, the ventilation status of occluded lung segments and the compensatory function of other lung tissues. Combined with the above information, we comprehensively judged the tolerance of patients to the implanted prosthesis and the overall impact on airway and pulmonary function.

Statistical analysis

Because this was a small retrospective case series, patient characteristics, procedural outcomes and follow-up events were summarized descriptively. No inferential statistical comparisons were performed.

Results

All 4 enrolled patients successfully received bronchoscopic placement of custom-made sutured artificial prosthesis. The operations were performed smoothly. No severe intraoperative complications including airway laceration, massive hemorrhage, asphyxia or cardiopulmonary arrest occurred. All patients completed 12-month systematic follow-up. The immediate hemostatic effect, hemoptysis recurrence, postoperative complications, imaging changes and general tolerance were comprehensively analyzed based on clinical and imaging data.

Baseline Data of Enrolled Patients

The baseline information, characteristics of hemoptysis, previous treatment history and etiological distribution of the 4 patients are shown in Table 1. The enrolled cases included patients of different ages and genders. The causes of hemoptysis involved lung cancer cavity, aortic malformation combined with tracheal fistula and diaphragmatic arterial tracheal fistula. All patients suffered persistent hemoptysis after conventional hemostatic drugs and bronchial artery embolization. The daily hemoptysis volume ranged from 20 to 50 mL, and the disease course was 1 to 11 months. All cases met the inclusion criteria of refractory tracheal hemoptysis.

Table 1
Baseline clinical data of 4 patients

Case No.	Gender	Age (years)	Etiology of hemoptysis	Duration of hemoptysis	Daily hemoptysis volume (mL)	Previous interventions	Outcomes after arterial embolization
1	Male	60	Pulmonary cancer cavity	6 months	50	Hemostatic drugs + Pulmonary artery embolization	Hemoptysis recurred 1 month after operation
2	Female	75	Pulmonary cancer	3 months	20–30	Hemostatic drugs + Arteriography	Embolization was not performed
3	Male	73	Aortic malformation combined with tracheal fistula	1 month	50	Hemostatic drugs + Arteriography	Embolization failed after angiography
4	Female	54	Diaphragmatic arterial tracheal fistula	11 months	20	Hemostatic drugs + Arteriography	Embolization was not performed

Immediate and Short-term Therapeutic Efficacy

The placement position of the prosthesis in each patient was completely consistent with the bleeding segmental bronchus localized by preoperative enhanced chest CT. The prostheses were deployed at the anterior segment of the right upper lobe, anterior basal segment of the right lower lobe, dorsal segment of the left lower lobe and basal segment of the right lower lobe respectively. The time to complete hemostasis differed among cases. Hemoptysis of Case 1 was completely controlled within 24 hours after prosthesis placement, while the other 3 patients achieved complete hemostasis within 36 hours. The overall immediate hemostasis rate reached 100%, as shown in Table 2.

Table 2
Prosthesis placement sites and immediate hemostatic effects of each patient

Case No.	Bleeding segmental bronchus	Prosthesis placement site	Time to hemostasis	Immediate therapeutic effect
1	Anterior segment of right upper lobe	Anterior segment of right upper lobe	24 h postoperatively	Complete hemostasis
2	Anterior basal segment of right lower lobe	Anterior basal segment of right lower lobe	36 h postoperatively	Complete hemostasis
3	Dorsal segment of right lower lobe	Dorsal segment of left lower lobe	36 h postoperatively	Complete hemostasis
4	Basal segment of right lower lobe	Anterior basal segment of right lower lobe	36 h postoperatively	Complete hemostasis

Long-term Recurrence of Hemoptysis (Follow-up at 3, 6 and 12 Months)

Outpatient reexamination and telephone follow-up were conducted at 3, 6 and 12 months after surgery. Chest CT and bronchoscopy were performed to evaluate the recurrence of hemoptysis. During the 12-month follow-up period, no case of hemoptysis recurrence was observed, indicating stable long-term hemostatic efficacy. The detailed results are shown in Table 3.

Table 3
Recurrence of hemoptysis at different postoperative time points

Follow-up time	Total cases	Cases with recurrence	Cases without recurrence	Recurrence rate (%)
3 months postoperatively	4	0	4	0.00
6 months postoperatively	4	0	4	0.00
12 months postoperatively	4	0	4	0.00

Postoperative Complications

Vital signs and symptoms such as cough and chest distress were closely monitored after surgery. Imaging and endoscopic examinations were used to assess prosthesis position and airway conditions. Only Case 1 developed transient low-grade fever within 24 hours after surgery, with the maximum body temperature of 38.1°C. The fever subsided rapidly after symptomatic antipyretic treatment. No prosthesis displacement or shedding, airway obstruction, aggravated pulmonary infection, pulmonary atelectasis, pneumothorax or other severe complications occurred in all patients. The details of complications are listed in Table 4.

Table 4
Incidence of postoperative complications

Type of complication	Cases occurred	Incidence rate (%)	Intervention	Outcome
Transient low-grade fever	1	25.00	Symptomatic antipyretic treatment	Body temperature returned to normal within 24 h
Prosthesis displacement/ shedding	0	0.00	—	—
Airway obstruction	0	0.00	—	—
Aggravated pulmonary infection	0	0.00	—	
Pneumothorax/Pulmonary atelectasis	0	0.00	—	—

Imaging and Airway Follow-up Results

Chest CT scans were performed at 7 days, 3 months, 6 months and 12 months after surgery to dynamically observe the position of prostheses, morphology of segmental bronchi and pulmonary ventilation function. During the entire follow-up period, all artificial prostheses were firmly fixed in the target bronchi without displacement or shedding, which was attributed to the anti-slip sutures applied during fabrication. The prostheses fitted closely with the airway wall. No obvious atelectasis was found in the distal lung tissue of the occluded segment, and the ventilation of other lung lobes remained normal. None of the patients presented persistent chest distress, shortness of breath or decreased exercise tolerance, suggesting good pulmonary tolerance. The hematoma in the original bleeding region was gradually absorbed, and abnormal imaging manifestations were improved over time.

Overall Prognosis and Quality of Life

After the 12-month follow-up, comprehensive evaluation on patients' subjective symptoms and daily activities was carried out. The symptoms of cough and expectoration were significantly relieved in all 4 patients. No recurrent chest distress or wheezing was reported. Daily activities, diet and sleep were not affected, and exercise capacity was markedly improved compared with that before treatment. This minimally invasive occlusion therapy can achieve effective hemostasis while preserving the function of normal lung tissue to the maximum extent, leading to a remarkable improvement in patients' long-term quality of life.

Discussion

Refractory tracheal hemoptysis has long been recognized as one of the most intractable clinical challenges in critical respiratory medicine. This acute disorder manifests with rapid disease progression, and massive bleeding can instantly trigger a series of life-threatening complications including complete airway obstruction, severe asphyxia and hypovolemic hemorrhagic shock, which explains its consistently high clinical mortality rate worldwide [21]. To address this condition, a comprehensive multi-tiered therapeutic framework has been developed in modern clinical practice, covering pharmacotherapy, bronchial artery embolization (BAE), surgical resection and diverse bronchoscopic interventional techniques. Nonetheless, every existing treatment option carries distinct drawbacks and application constraints that cannot be ignored. Vasoactive medications serve as the fundamental hemostatic agents for routine hemoptysis management, yet their therapeutic efficacy is notably limited when dealing with bleeding induced by vascular malformations, pulmonary cancer cavities and arteriovenous fistulas. Moreover, these drugs tend to induce various cardiovascular side effects, and they are strictly contraindicated for patients suffering from hypertension, coronary heart disease and cardiac arrhythmia, which further narrows their safe clinical scope [22]. As the first-line interventional approach for massive hemoptysis, BE achieves a short-term hemostatic success rate between 70% and 99%, but it still faces prominent technical shortcomings. When the bleeding originates from the aorta, diaphragmatic artery and other systemic arterial branches, conventional angiography often fails to accurately locate the culprit vessels, resulting in a high rate of embolization failure [23]. Additionally, postoperative vascular recanalization and the formation of new collateral circulation are the primary contributors to recurrent hemoptysis. Multiple published studies have indicated that the hemoptysis recurrence rate after BE ranges from 15% to 39%, and a considerable number of patients experience rebleeding shortly after the procedure [24]. While pulmonary lobectomy and segmentectomy can deliver radical hemostatic outcomes, such open surgeries bring about extensive tissue trauma and high anesthetic risks. Patients with poor pulmonary reserve, multiple chronic comorbidities or advanced malignant tumors generally lack the physical tolerance to undergo major surgical procedures, which

drastically restricts the clinical promotion of radical surgery [25]. Given the unsatisfactory performance of current mainstream treatments for refractory tracheal hemoptysis, there is an urgent clinical demand to explore a novel remedial therapy that combines minimal invasiveness, reliable efficacy, favorable safety and broad applicability, so as to fill the treatment gap and improve the prognosis of this high-risk patient population.

Analysis of baseline characteristics and treatment strategy of the enrolled cases

A total of four patients diagnosed with refractory tracheal hemoptysis were recruited for this retrospective clinical study. The enrolled cases presented diversified underlying etiologies, covering pulmonary cancer cavity, aortic malformation complicated with tracheal fistula, and diaphragmatic arterial tracheal fistula. These three categories are widely recognized as the most challenging types of hemoptysis in clinical practice, which typically yield unsatisfactory therapeutic outcomes when treated with conventional hemostatic medications and bronchial artery embolization (BAE) [26]. The daily hemoptysis volume of the participants ranged from 20 to 50 mL, and their disease duration varied extensively from 1 month to 11 months. All patients had undergone standardized systemic hemostatic drug therapy as the first-line treatment. Among them, several individuals further received pulmonary artery embolization and selective bronchial arteriography. Despite sequential application of multiple conventional interventions, their hemoptysis symptoms persisted and failed to achieve effective control. All enrolled cases fully complied with the diagnostic criteria for refractory hemoptysis stipulated in the domestic Expert Consensus on Diagnosis and Treatment of Massive Hemoptysis, confirming the rationality of case selection in this research [27].

From the perspective of pathological anatomy, each type of lesion has distinct characteristics that lead to treatment resistance. For patients with pulmonary cancer cavity, the tumor tissue itself is inherently fragile. The cavity wall is destructed and accompanied by extensive proliferation of disordered neovasculature. Given the large quantity and intricate branching of feeding vessels around the lesion, conventional BE can hardly achieve complete embolization of all tiny vascular branches. Residual microvessels after intervention are highly likely to trigger recurrent bleeding, which accounts for the high failure rate of embolization for such patients [28]. As for tracheal fistulas induced by aortic and diaphragmatic arterial malformations, the abnormal vascular communications belong to systemic circulatory branches rather than normal bronchial arteries. These blood vessels usually follow tortuous and hidden courses. During interventional angiography, it is difficult for clinicians to accurately identify and locate the fistula vessels, which frequently results in missed diagnosis and subsequent embolization failure. This is the core anatomical factor contributing to the poor efficacy of BAE for vascular fistula-related hemoptysis.

Fortunately, all bleeding lesions in this patient cohort were located in segmental bronchi, which are within the reach of both rigid and flexible bronchoscopes. Such anatomical features laid a solid and favorable foundation for the implementation of endobronchial occlusion therapy. Prior to surgery, all patients received enhanced chest CT combined with three-dimensional airway reconstruction as a routine preoperative assessment. This comprehensive imaging modality can clearly delineate the scope of bleeding lesions, precisely measure the inner diameter and running course of target bronchi, and visualize the spatial relationship between lesions and adjacent great vessels. This standardized preoperative evaluation effectively eliminates the risks brought by blind intraoperative operation, and has gradually become a routine and essential procedure for bronchoscopic intervention targeting hemoptysis in contemporary clinical practice [29].

All surgical procedures were performed by senior physicians with rich experience in interventional pulmonology. General anesthesia was adopted for every case to stabilize patients' vital signs and eliminate spontaneous cough reflex during operation. According to the individual airway structure and lesion location of each patient, the operators flexibly chose rigid bronchoscope or flexible bronchoscope to guarantee sufficient operative visual field and operational flexibility. All four surgeries were accomplished successfully in a single attempt. No intraoperative adverse events such as airway laceration, massive hemorrhage, sharp decline in blood oxygen saturation or cardiopulmonary instability occurred throughout the procedures. The smooth operation process and clean intraoperative safety records fully verified that this custom-made prosthesis implantation technique possesses reliable operational safety even when applied to complex refractory hemoptysis cases with diverse etiologies. It also proves that the whole set of preoperative evaluation, intraoperative manipulation and equipment selection protocols formulated in this study are scientific and feasible for clinical application.

Hemostatic mechanism and structural advantages of custom-made sutured artificial prosthesis

The occlusive prosthesis adopted in this study was manufactured from medical-grade silica gel. According to the individual anatomical characteristics of patients' airways measured by preoperative imaging data, the raw materials were tailored into a standard conical structure and then reinforced and shaped with clinical non-absorbable surgical sutures. The overall design concept of this custom-made device draws on the mature research findings and extensive clinical application experience of various existing endobronchial occlusive instruments at home and abroad, and it has been further optimized and innovated for the treatment of refractory hemoptysis [30]. When compared with conventional balloon tamponade devices and imported commercial bronchial spigots, this sutured silica gel prosthesis exhibits prominent strengths in both hemostatic mechanisms and physical structural design. Its comprehensive hemostatic capacity is jointly realized via three interrelated pathways, namely mechanical occlusion, hemodynamic regulation and local procoagulant action.

Mechanical occlusion serves as the core hemostatic mechanism of the prosthesis. The conical outline enables the device to fit tightly against the inner wall of segmental bronchi. On this basis, it can thoroughly isolate bleeding lesions from the central airway and completely block the passage of flowing blood. Meanwhile, the prosthesis exerts persistent gentle compression on the damaged mucosal surface and blood vessels, which effectively reduces the shear force of blood flow on the rupture site and accelerates the closure of injured blood vessels [31]. Unlike balloon catheters that are only suitable for short-term temporary compression and must be removed within a limited period, medical silica gel boasts outstanding biocompatibility and tissue compatibility. It can be safely indwelled in the airway for a long time to achieve permanent endobronchial occlusion, which perfectly satisfies the long-term treatment requirements of patients with intractable and recurrent hemoptysis [32].

The second major function is hemodynamic regulation. After the target bronchus is fully occluded, a relatively closed cavity is formed at the bleeding site. Blood gradually accumulates inside the cavity and results in local blood stasis, which raises the regional venous pressure. The elevated venous pressure can counteract the arterial perfusion pressure, thereby reducing the inflow of arterial blood to the lesion site and producing a passive hemostatic effect. This mechanism plays a particularly vital role in controlling hemoptysis caused by airway vascular fistulas with high-pressure blood flow [33]. In addition, the stable local microenvironment created by occlusion eliminates the continuous impact of airflow and inrushing blood on the wound surface.

Under such favorable conditions, platelets and various coagulation factors in the blood can gather and adhere normally around the bleeding point, which triggers and accelerates the formation of stable thrombi. This indirect procoagulant effect further consolidates the hemostatic outcome and prevents secondary bleeding [34].

In terms of structural optimization, the prosthesis is designed with three targeted improvements. First, the conical shape complies with the physiological anatomical feature that human segmental bronchi gradually narrow from the proximal end to the distal end. Compared with cylindrical occlusive devices, it achieves a higher fitting degree and is less prone to displacement caused by regular respiratory movement and patient coughing [35]. Second, anti-slip sutures are wrapped around the middle section of the prosthesis. The rough surface of the sutures increases the friction between the prosthesis and airway mucosa, effectively solving the common defect that pure silica gel devices tend to slip due to their smooth surface [36]. Third, a traction loop is sewn at the tail end of the prosthesis. This structure makes it convenient for bronchoscopic forceps to grasp, deliver and position the device during surgery, and also allows for safe removal of the prosthesis if adverse reactions occur during long-term indwelling, which greatly enhances the operability and reversibility of the device [37].

As reported in existing literature, the commercially available Watanabe spigot is a classic imported airway occlusive device with reliable clinical efficacy, yet it has obvious drawbacks including limited supply channels and fixed specifications that cannot be adjusted according to individual airway differences [38]. In contrast, the medical silica gel used in this study is a routine clinical material with wide accessibility and low procurement cost. Clinicians can cut and shape the prosthesis on site based on bronchial diameters measured by CT scans to match personalized airway anatomy, so this technique is highly applicable to primary medical institutions and regions with limited medical resources [39]. From the perspective of material safety, medical silica has stable chemical properties and low tissue irritability. A large number of clinical studies on silica gel airway implants have verified that long-term indwelling will not induce severe airway inflammation, mucosal hyperplasia or tissue fibrosis, thus providing solid material guarantee for the long-term safe application of this prosthesis [40].

Analysis of Immediate and Long-term Efficacy

All four patients diagnosed with refractory tracheal hemoptysis attained complete hemostasis between 24 and 36 hours after bronchoscopic implantation of custom-made artificial prostheses, yielding an immediate hemostatic success rate of 100%. A small number of patients did not stop bleeding immediately after the operation, and this transient phenomenon was neither caused by prosthesis displacement nor flawed surgical manipulation. Clinically, it is primarily ascribed to the gradual expulsion of residual blood and organized clots inside bleeding lesions, which is driven by the physiological ciliary movement and regular respiratory motion of the airway. This is a well-recognized postoperative feature of bronchoscopic endobronchial occlusion interventions and has been consistently reported in multiple domestic and international clinical studies focusing on similar techniques [41].

We designed a standardized follow-up protocol and performed comprehensive evaluations at 3, 6 and 12 months postoperatively, combining outpatient physical examinations, chest computed tomography (CT) scans and routine bronchoscopy. Over the entire 12-month follow-up period, none of the enrolled patients experienced recurrent hemoptysis, verifying the stable and reliable long-term hemostatic efficacy of this interventional approach. When compared with the clinical outcomes of mainstream conventional therapies, the advantages of our technique become more evident. Existing clinical data reveal that refractory hemoptysis patients treated solely with systemic hemostatic drugs have a 6-month recurrence rate of over 60%. Meanwhile, patients

undergoing bronchial artery embolization (BAE) present a 1-year hemoptysis recurrence rate as high as 39.0% [42]. In sharp contrast, our study recorded a 1-year recurrence rate of 0%, which strongly highlights the superior performance of permanent endobronchial occlusion in sustaining long-term disease control for refractory hemoptysis.

In terms of therapeutic mechanisms, both hemostatic medications and BAE belong to indirect hemostatic modalities. Systemic hemostatic drugs travel through the circulatory system to act on target blood vessels, merely inducing temporary vasoconstriction to mitigate bleeding risks, without addressing the fundamental pathological changes. BAE works by embolizing abnormal feeding arteries, yet it cannot repair inherent anatomical defects associated with primary lesions such as malignant lung cavities and airway vascular fistulas. Following embolization, neovascularization and collateral circulation are prone to develop around the lesions, which are major contributors to recurrent hemoptysis [43].

Distinct from these conventional strategies, the artificial prosthesis achieves hemostasis via direct physical occlusion of the affected segmental bronchus, thoroughly cutting off the bleeding pathway. Its therapeutic effect is not compromised by persistent primary lesions, newly formed blood vessels or reconstructed collateral circulation, which accounts for its excellent curative effect in patients who previously failed BAE treatment. Serial postoperative chest CT examinations confirmed that all implanted prostheses stayed firmly in place without displacement or shedding. No extensive pulmonary atelectasis was observed in the occluded bronchial segments. The human respiratory system has powerful functional compensation; occlusion of a single segmental bronchus imposes negligible influence on overall pulmonary ventilation. During follow-up visits, all patients maintained satisfactory exercise tolerance and normal respiratory function. Symptoms including cough and chest distress were markedly alleviated, and their overall quality of life was greatly improved compared with the preoperative state. To sum up, this minimally invasive technique successfully fulfills the dual clinical objectives of effective hemostasis and full preservation of normal pulmonary physiological function [44].

Safety Evaluation of Complications

Safety is a core criterion for evaluating interventional respiratory techniques and a key factor determining their clinical promotion, as well as an important consideration for clinicians when selecting treatment regimens for patients with refractory hemoptysis. We conducted comprehensive postoperative monitoring and follow-up for the four patients who underwent implantation of custom-made sutured prostheses. Only one patient developed transient low-grade fever within 24 hours after surgery, with a peak body temperature of 38.1°C. The body temperature returned to normal rapidly after routine symptomatic treatment. No prosthesis displacement or shedding, airway stenosis and obstruction, severe pulmonary infection, pneumothorax or pulmonary abscess occurred in any case. The overall incidence of adverse events was 25.0%, and all symptoms were mild and self-limiting without affecting patients' recovery. Based on clinical and pathological analysis, this transient fever was induced by mild mechanical stimulation of airway mucosa and local sterile inflammation caused by the implanted prosthesis, rather than bacterial infection. This is a common transient physiological reaction after endobronchial foreign body implantation, which has been widely reported in similar airway interventional studies [45].

By reviewing complication data of other mainstream airway interventional devices and therapies reported at home and abroad, obvious risks can be found in existing approaches. Traditional bronchoscopic balloon

tamponade tends to cause airway mucosal erosion and ulceration due to long-term compression, and its safety risks increase with prolonged indwelling. The incidence of pneumothorax after endobronchial valve implantation ranges from 4% to 18%, which will further aggravate patients' respiratory burden [46]. As a classic interventional therapy for hemoptysis, BAE may lead to severe complications including spinal cord injury and ectopic embolism. Surgical lobectomy or segmentectomy is associated with multiple risks such as incision infection and postoperative respiratory failure, and it is poorly tolerated by high-risk patients [47]. In comparison, the custom-made sutured silicone prosthesis used in this study is featured with fewer types of complications and no severe adverse events, showing remarkable overall safety advantages.

The excellent safety profile of this technique is guaranteed by standardized design and rigorous operative management. Firstly, preoperative enhanced chest CT is used to accurately measure the diameter and morphology of target bronchi, so that the prosthesis can be customized to fit the airway perfectly and avoid excessive compression and ischemic injury to airway mucosa. Secondly, medical silicone has excellent biological inertness and causes much less irritation to airway epithelial cells than plastic and metal materials. Thirdly, all operations are performed under general anesthesia, which reduces cough and restlessness during surgery and lowers the risk of intraoperative prosthesis displacement. Standardized application of antitussive drugs after surgery can effectively prevent prosthesis shedding and airway injury caused by severe cough [48]. The 12-month long-term follow-up further verified that all prostheses were firmly fixed in place. The anti-slip sutures wrapped around the middle part of the prosthesis functioned well, which effectively solved the common safety hazard of easy slippage of traditional occlusive devices.

Differences in Therapeutic Effects among Patients with Various Etiologies

This study enrolled patients with three typical causes of refractory tracheal hemoptysis, including lung cancer cavity, aortic malformation combined with tracheal fistula, and diaphragmatic arterial tracheal fistula. Satisfactory overall therapeutic effects were achieved in all cases, while the underlying hemostatic mechanisms varied slightly due to different lesion characteristics.

Pulmonary cancer cavity is a common cause of refractory hemoptysis. The tissue of cancer cavities is fragile, with abundant and disordered neovascularization, and the bleeding points are diffusely distributed. For such patients, BE can hardly embolize all tiny neovascular branches thoroughly. Residual microvessels are highly likely to cause recurrent bleeding after intervention [49]. In contrast, the conical sutured prosthesis can be precisely implanted into the segmental bronchus where the cancer cavity is located to completely block the outflow of blood. Meanwhile, the blood retained inside the cavity will gradually coagulate and organize, forming firm thrombi to reinforce the bleeding surface. This dual hemostatic effect makes up for the deficiency of BAE in treating diffuse bleeding lesions.

For patients with aortic malformation complicated with tracheal fistula and diaphragmatic arterial tracheal fistula, the bleeding originates from high-pressure blood flow of systemic circulation that directly ruptures into the airway. Conventional hemostatic drugs act on systemic blood vessels and cannot block the high-pressure blood flow at fistulas. BAE is limited to the bronchial arterial system and fails to intervene in aortic and diaphragmatic arterial branches. Therefore, both treatments show poor efficacy for this type of hemoptysis [50]. The silicone prosthesis placed at the distal end of the fistula acts as a stable physical barrier. It buffers the

continuous impact of high-pressure blood flow on the damaged airway, reduces local blood pressure, and creates favorable conditions for the repair of fistula and surrounding tissues.

It can be concluded that this prosthesis implantation technique is not restricted by the source of bleeding vessels. As long as the bleeding focus is located in the segmental bronchus accessible to bronchoscopy, it can exert stable therapeutic effects regardless of bronchial arterial or systemic arterial bleeding. Its application scope is far broader than BAE. In clinical practice, refractory hemoptysis is often characterized by complex etiologies, occult bleeding vessels and multi-source bleeding, which are the main reasons for the failure of conventional treatments. This technique targets the lesion-bearing airway instead of relying on the identification and embolization of feeding vessels, which fully meets the clinical treatment demands of refractory and multi-source hemoptysis and possesses high clinical application and promotion value for complex cases with failed conventional therapies.

Comprehensive Advantages over Conventional Therapies

Combining the clinical data of this study and previously published literature, bronchoscopic implantation of custom-made sutured artificial prostheses presents prominent comprehensive advantages in five key dimensions: therapeutic efficacy, safety, economic benefits, operational difficulty and scope of application. In terms of therapeutic efficacy, this technique achieves immediate hemostasis combined with zero long-term recurrence, which effectively addresses the inherent drawbacks of conventional hemostatic drugs with transient effects and bronchial artery embolization (BAE) with a high recurrence rate. For intractable cases such as vascular fistulas and pulmonary cancer cavities that fail to respond to arterial embolization, this therapy serves as an optimal remedial intervention, delivering sustained and reliable hemostatic outcomes throughout the follow-up period.

In terms of safety, the whole procedure is implemented via bronchoscopic minimally invasive manipulation. It avoids the severe surgical trauma associated with lobectomy or segmentectomy, as well as ionizing radiation exposure brought by interventional radiological operations like BAE. The adverse reactions observed in this study were mild and could be rapidly relieved after symptomatic management. Elderly patients, debilitated individuals and those complicated with multiple chronic underlying diseases, who are usually classified as high-risk groups for invasive treatment, can well tolerate this minimally invasive approach.

From an economic perspective, the occlusive prosthesis is fabricated using commonly used medical silicone and routine surgical sutures, with extremely low raw material costs. There is no need to purchase expensive imported dedicated airway occlusive devices, which greatly cuts down the medical expenditure on consumables. Additionally, favorable long-term hemostatic efficacy eliminates the need for repeated hospitalization, reexamination and multiple interventional treatments, further reducing the long-term medical burden on patients. This cost-effective characteristic fully conforms to the development requirements of hierarchical medical systems and public health economics in China.

In terms of operational feasibility, the procedure only requires conventional rigid and flexible bronchoscopes that are widely equipped in respiratory departments. No large-scale interventional equipment or special high-value consumables are needed. The overall operational process is concise and standardized. Respiratory

intervention physicians can master the core procedures after short-term professional training, which greatly lowers the threshold for clinical promotion and popularization at various levels of medical institutions.

Regarding the scope of application, this technique breaks through the limitation of BAE, which is only applicable to bronchial arterial bleeding. It works effectively for non-bronchial arterial hemorrhage, angiographically occult hemoptysis and recurrent hemoptysis after multiple interventional treatments. Meanwhile, it has relatively lenient requirements on patients' pulmonary function, making up for the narrow application range of surgical resection that excludes patients with poor respiratory reserve.

In addition to practical advantages, this therapy also embodies advanced technical concepts. It strictly adheres to the core principle of modern interventional pulmonology of "focusing on lesions and basing treatment on anatomical characteristics". A complete standardized treatment chain has been established, including preoperative precise localization via chest CT, accurate intraoperative endoscopic manipulation and standardized postoperative management, which is highly consistent with the mainstream development trend of precision interventional medicine. At present, commercial standardized medical devices can hardly adapt to the individual anatomical differences of the airway among different patients. The on-site cutting and shaping of prostheses according to individual airway conditions in this study is a typical practice of personalized minimally invasive treatment. It provides valuable references for the research, development and clinical application of similar endobronchial interventional techniques, and has good reference value for the optimization and innovation of airway intervention devices and treatment schemes in the future.

Technical Notes and Clinical Operating Specifications

Combined with the operational experience of the four cases in this study and relevant literature, standardized operating specifications must be strictly implemented to guarantee the efficacy and safety of this technique in clinical practice.

First and foremost, adequate preoperative evaluation and accurate localization serve as the fundamental prerequisite. Enhanced chest CT combined with three-dimensional airway reconstruction shall be performed routinely. This examination enables clinicians to precisely identify the location, diameter and course of the bleeding segmental bronchus, as well as the spatial relationship between lesions, great vessels and the tracheal carina. Occlusion of the main bronchus or lobar bronchus is contraindicated, since it will easily lead to severe ventilatory dysfunction. Therefore, this technique is only applicable to lesions located in segmental bronchi and more distal airways. In addition, comprehensive assessments of patients' coagulation function, cardiac and pulmonary function should be completed to fully evaluate and control anesthesia risks before the procedure.

Second, individualized fabrication of the prosthesis is required. The prosthesis is tailored according to the bronchial diameter measured by preoperative CT. Its overall size is slightly larger than the inner diameter of the target bronchus, so as to achieve tight fitting relying on the elasticity of silica gel. Anti-slip sutures and traction loops shall be sewn in a standardized manner with firm knots, preventing suture detachment during the operation.

Third, standard intraoperative procedures should be followed. General anesthesia is recommended to suppress patients' cough reflex. Before prosthesis placement, intraluminal blood and clots must be thoroughly aspirated to maintain a clear operative field, which prevents poor adhesion caused by residual clots. The prosthesis

should be delivered gently to avoid scratch and injury to the airway mucosa. After placement, repeated endoscopic examination is necessary to confirm complete occlusion and stable position of the prosthesis before withdrawing the bronchoscope.

Fourth, standardized postoperative management is crucial for long-term safety. Antitussive medications are routinely administered within 72 hours postoperatively. Patients are instructed to avoid severe cough and straining, which is the key measure to prevent early prosthesis displacement. Vital signs including body temperature, respiratory status and sputum production are monitored continuously. For transient low-grade fever induced by local sterile inflammation, only symptomatic treatment is adopted, and broad-spectrum antibiotics shall not be used blindly. Long-term follow-up protocols are formulated, and chest CT reexaminations are scheduled at 3, 6 and 12 months after surgery to dynamically monitor the prosthesis position, pulmonary morphology and the recurrence of hemoptysis, so that potential adverse conditions can be detected in a timely manner.

Fifth, indications and contraindications must be strictly defined. **Indications**: Refractory segmental bronchial hemoptysis unresponsive to conventional hemostatic drugs and bronchial artery embolization; hemoptysis caused by lung cancer cavity and airway vascular fistula; non-bronchial arterial hemorrhage; patients who cannot tolerate surgical resection. **Contraindications**: Bleeding located in the main bronchus or lobar bronchus; severe airway stenosis or malformation that makes prosthesis placement impossible; patients with severe respiratory failure requiring continuous mechanical ventilation; patients with severe systemic coagulation disorders.

Analysis of Study Limitations

This is a single-center retrospective clinical study with several inherent limitations. First, the sample size was small, with only 4 patients enrolled. Despite satisfactory short-term and long-term therapeutic outcomes, the representativeness of the samples is limited. Further multi-center and large-sample clinical studies are required to verify the general applicability and long-term safety of this technique, as well as to explore differences in efficacy among patients with various etiologies and airway anatomical characteristics. Second, the follow-up period of this study was 12 months, which only allowed evaluation of the efficacy and safety within one year. Long-term observations with extended follow-up are still needed to assess the status of the prosthesis during prolonged indwelling (2 years, 3 years), chronic inflammatory changes in the airway, and long-term secondary pulmonary lesions. Third, no control group was established in this study. Hence, head-to-head comparisons of efficacy and safety between this technique and mainstream treatments such as bronchial artery embolization and commercial airway occlusion devices were not conducted. Prospective controlled studies should be designed in subsequent research to quantitatively analyze the advantages of this technique. Fourth, all prostheses in this study were manually trimmed and sutured. Slight artificial deviations existed in the size and shape of prostheses fabricated by different operators. In the future, three-dimensional printing technology can be adopted to produce integrated silicone prostheses customized precisely based on patients' CT data. This will improve the fitting accuracy between prostheses and airways and reduce operational errors. Fifth, this study failed to conduct in-depth exploration on subtle changes in airway microecology and pulmonary function after prosthesis indwelling. Relevant assessment indicators including pulmonary function tests and airway secretion culture can be added in follow-up research to optimize the evaluation system from the perspectives of functional assessment and microbiology.

Clinical Prospects

Refractory tracheal hemoptysis has long been a challenging clinical problem for departments of respiratory medicine and interventional radiology due to its complex etiologies and poor response to conventional therapies. This study verified that bronchoscopic implantation of custom-made sutured silicone prostheses can achieve immediate hemostasis and long-term disease control for refractory hemoptysis via the dual mechanisms of physical occlusion and local blood flow regulation.

Featuring minimal invasiveness, high efficacy, favorable safety profile, cost-effectiveness and easy popularization, this technique overcomes multiple limitations of pharmacotherapy, bronchial artery embolization and surgical procedures. It possesses unique clinical value for special types of refractory hemoptysis, such as hemoptysis caused by lung cancer cavities and aorto/diaphragmatic arteriotracheal fistula. As a primary salvage regimen when conventional treatments fail, it is worthy of promotion and application in medical institutions at all levels, especially primary hospitals, oncology hospitals and thoracic hospitals.

From the perspective of technological development, endoscopic airway occlusion has become a key direction for interventional treatment of hemoptysis. On the basis of this study, further optimization and exploration can be carried out in the future. First, advanced technologies including virtual bronchoscopic navigation and electromagnetic navigation can be applied to improve the positioning accuracy of target bleeding bronchi and the success rate of prosthesis placement, as well as reduce operational difficulty. Second, prosthesis materials can be optimized. Loading hemostatic and anti-inflammatory drugs onto silicone substrates may realize the synergistic effect of physical occlusion and local sustained drug release, so as to reduce complications and enhance hemostatic efficacy. Third, unified manufacturing criteria for prostheses should be established. Standardized molds and three-dimensionally printed individualized prostheses can be developed to eliminate errors caused by manual production and promote the standardization of this technique. Fourth, multi-center cohort studies need to be conducted to clarify the optimal indications, absolute and relative contraindications, formulate unified operational guidelines, and eventually establish a standardized clinical diagnosis and treatment system.

Conclusions

In conclusion, given the limited therapeutic options currently available for refractory hemoptysis, bronchoscopic implantation of custom-made sutured prostheses is a minimally invasive technique with high potential for clinical translation. The preliminary clinical data from this study provides practical evidence for its clinical application. Further large-sample clinical studies with long-term follow-up are expected to continuously improve the technical system. This will offer more safe and effective treatment options for patients with refractory tracheal hemoptysis and facilitate the personalized development of respiratory interventional therapy.

Abbreviations

BAE
bronchial artery embolization
CT
computed tomography

SI
International System of Units.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Xianyang Central Hospital (approval no. 2025-IRB-45). Written informed consent to participate was obtained from all patients.

Consent for publication

Written informed consent for publication of the patients' clinical details and accompanying images was obtained from all patients.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

TG and JL contributed to the conception and design of the study. JL and XH provided administrative support. JL provided study materials or patients. TG and XH collected and assembled the data and analysed and interpreted the data. TG drafted the manuscript. TG, XH and JL read and approved the final manuscript.

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References

1. Jin F, Li Q, Bai C, Wang H, Li S, Song Y, Zeng Y, Zhou R, Li W, Hu C, Zhang J, Zhou H, Zhang H. Chinese Expert Recommendation for Diagnosis and Treatment of Massive Hemoptysis. Respiration. 2020;99(1):83-92. doi:

10.1159/000502156. Epub 2019 Sep 11. PMID: 31509823.

2. Keshmiri MS, Astani B, Hosseini-Baharanchi FS, Sharif-Kashani B, Ahmadinia M, Mohammadi S, Ranjbar S, Saliminejad L, Shafaghi S. Efficacy of bronchial artery embolization in hemoptysis: longitudinal studyon survival and recurrence. CVIR Endovasc. 2025 Dec 13;8(1):111. doi: 10.1186/s42155-025-00627-x. PMID: 41389100; PMCID: PMC12701884.
3. Luo L, Luo J, Jiang Y. A retrospective analysis of risk factors for massive hemoptysis in patients with bronchiectasis. BMC Pulm Med. 2022 Jun 2;22(1):214. doi: 10.1186/s12890-022-02006-x. PMID: 35650568; PMCID: PMC9161452.
4. Mejri I, Boubaker N, Znegui T, Daboussi S, Aichaouia C, Mhamdi S, Moatemri Z. Massive Haemoptysis Treated with Bronchial Artery Embolisation in COVID-19 Infection. Eur J Case Rep Intern Med. 2022 Aug 1;9(8):003475. doi: 10.12890/2022_003475. PMID: 36093306; PMCID: PMC9451510.
5. Gupta A, Hadziomerovic A. Embolotherapy in Bronchial Hemorrhage. Thorac Surg Clin. 2021 Aug;31(3):323-332. doi: 10.1016/j.thorsurg.2021.04.012. Epub 2021 Jun 10. PMID: 34304841.
6. Li H, Ding X, Zhai S, Gao K. A retrospective study on the management of massive hemoptysis by bronchial artery embolization: risk factors associated with recurrence of hemoptysis. BMC Pulm Med. 2023 Mar 16;23(1):87. doi: 10.1186/s12890-023-02371-1. PMID: 36927574; PMCID: PMC10018857.
7. Prey B, Francis A, Williams J, Krishnadasan B. Evaluation and Treatment of Massive Hemoptysis. Surg Clin North Am. 2022 Jun;102(3):465-481. doi: 10.1016/j.suc.2021.11.002. PMID: 35671767.
8. Davidson K, Shojaee S. Managing Massive Hemoptysis. Chest. 2020 Jan;157(1):77-88. doi: 10.1016/j.chest.2019.07.012. Epub 2019 Jul 30. PMID: 31374211.
9. Deshwal H, Sinha A, Mehta AC. Life-Threatening Hemoptysis. Semin Respir Crit Care Med. 2021 Feb;42(1):145-159. doi: 10.1055/s-0040-1714386. Epub 2020 Aug 30. PMID: 32862418.
10. Abid N, Loukil M, Mokni A, Badri I, Bouzaidi K, Ghrairi H. Outcomes of bronchial artery embolization for the management of hemoptysis. Tunis Med. 2021 Feb;99(2):264-268. PMID: 33899197; PMCID: PMC8636964.
11. Mowat A, Balbirsingh V, Sandhar P, Parekh M, Amlani A, Young B, Giblett N. Rigid bronchoscopy: a consultant survey. Ann R Coll Surg Engl. 2024 Apr;106(4):377-384. doi: 10.1308/rcsann.2023.0067. Epub 2023 Oct 16. PMID: 37843132; PMCID: PMC10981987.
12. Charya AV, Holden VK, Pickering EM. Management of life-threatening hemoptysis in the ICU. J Thorac Dis. 2021 Aug;13(8):5139-5158. doi: 10.21037/jtd-19-3991. PMID: 34527355; PMCID: PMC8411133.
13. Chen L, Fasolka B. Caring for patients with life-threatening hemoptysis. Nursing. 2024 Feb 1;54(2):44-47. doi: 10.1097/01.NURSE.0000997996.22052.79. PMID: 38271131.
14. Kathuria H, Hollingsworth HM, Vilvendhan R, Reardon C. Management of life-threatening hemoptysis. J Intensive Care. 2020 Apr 5;8:23. doi: 10.1186/s40560-020-00441-8. PMID: 32280479; PMCID: PMC7132983.
15. Le Tat T, Carlier R, Zhang N, Bouchet A, Amar R, Zhou J, El Hajjam M. Endovascular Management of Life-Threatening Hemoptysis in Primary Lung Cancer: A Retrospective Study. Cardiovasc Intervent Radiol. 2023 Jul;46(7):891-900. doi: 10.1007/s00270-023-03488-w. Epub 2023 Jun 13. PMID: 37311841.
16. Correia S, Dionísio J, Duro da Costa JJ. Modified technique of endobronchial balloon tamponade for persistent hemoptysis. J Bronchology Interv Pulmonol. 2014 Oct;21(4):361-5. doi: 10.1097/LBR.0000000000000102. PMID: 25321460.

17. Xu W, Wang H, He H, Hu H, Lu H, Li G. Massive haemoptysis from right middle lobe bronchus managed by customized silicon stents. Respirol Case Rep. 2019 Mar 25;7(5):e00418. doi: 10.1002/rcr2.418. PMID: 30956792; PMCID: PMC6432486.
18. Hamada N, Mino H, Yamamoto C, Uno M, Okawa S, Higo H, Shibamoto K, Yuzurio S, Suwaki T. Successful hemostasis of intractable hemoptysis with endobronchial Watanabe spigots following endoscopic thrombin injection into the bleeding bronchus in an inoperable patient. Respir Investig. 2026 Mar 16:101388. doi: 10.1016/j.resinv.2026.101388. Epub ahead of print. PMID: 41846186.
19. Taoka M, Makimoto G, Umakoshi N, Ninomiya K, Higo H, Kato Y, Fujii M, Kubo T, Ichihara E, Ohashi K, Hotta K, Tabata M, Maeda Y, Kiura K. Massive hemoptysis in a post-operative patient with recurrent lung cancer successfully treated by the combination therapy of Endobronchial Watanabe Spigot and bronchial artery embolization. Respir Med Case Rep. 2022 May 23;38:101669. doi: 10.1016/j.rmcr.2022.101669. PMID: 35646587; PMCID: PMC9136182.
20. Zeng J, Wu X, Zhang M, Lin L, Ke M. Modified silicone stent for difficult-to-treat massive hemoptysis: a pilot study of 14 cases. J Thorac Dis. 2020 Mar;12(3):956-965. doi: 10.21037/jtd.2019.12.47. PMID: 32274164; PMCID: PMC7139086.
21. Ryuge M, Hara M, Hiroe T, Omachi N, Minomo S, Kitaguchi K, Youmoto M, Asakura N, Sakata Y, Ishikawa H. Mechanisms of recurrent haemoptysis after super-selective bronchial artery coil embolisation: a single-centre retrospective observational study. Eur Radiol. 2019 Feb;29(2):707-715. doi: 10.1007/s00330-018-5637-2. Epub 2018 Jul 19. PMID: 30054792; PMCID: PMC6302874.
22. O'Gurek D, Choi HYJ. Hemoptysis: Evaluation and Management. Am Fam Physician. 2022 Feb 1;105(2):144-151. PMID: 35166503.
23. Fan S, Cheng X, Wang X, Liu Y, He W, Chen H. Bronchial artery embolization versus conservative treatment for hemoptysis: a systematic review and meta-analysis. BMC Pulm Med. 2024 Aug 30;24(1):428. doi: 10.1186/s12890-024-03244-x. PMID: 39215233; PMCID: PMC11365234.
24. Dong Y, An J. Analysis of recurrence of risk factors after transcatheter bronchial artery embolization for hemoptysis. Ann Saudi Med. 2024 Nov-Dec;44(6):414-421. doi: 10.5144/0256-4947.2024.414. Epub 2024 Dec 5. PMID: 39651925; PMCID: PMC11627038.
25. Yang B, Huo A, Li L, Qiu H. Risk factors of hemoptysis recurrence after bronchial artery embolization and patient feedbacks. Turk Gogus Kalp Damar Cerrahisi Derg. 2025 Jul 21;33(3):357-364. doi: 10.5606/tgkdc.dergisi.2025.27140. PMID: 40936993; PMCID: PMC12421540.
26. Mizumori Y, Nakahara Y, Hirata N, Hiraoka R, Kominami R, Hirano K, Hanaoka K, Katsuda R, Miyake K, Kawamura T. Toward Easy and Rapid Bronchial Occlusion With an Endobronchial Watanabe Spigot: A New Technique Using a Guide Sheath and Curette. J Bronchology Interv Pulmonol. 2020 Apr;27(2):122-127. doi: 10.1097/LBR.0000000000000642. PMID: 31851015.
27. Expert Panel on Thoracic Imaging; Olsen KM, Manouchehr-Pour S, Donnelly EF, Henry TS, Berry MF, Boiselle PM, Colletti PM, Harrison NE, Kuzniewski CT, Laroia AT, Maldonado F, Pinchot JW, Raptis CA, Shim K, Tong BC, Wu CC, Kanne JP. ACR Appropriateness Criteria® Hemoptysis. J Am Coll Radiol. 2020 May;17(5S):S148-S159. doi: 10.1016/j.jacr.2020.01.043. PMID: 32370959.
28. Nishino T, Takizawa H, Nishioka K, Fujimoto K, Miyamoto N, Aoyama M, Sawada T, Kawakita N, Kajiura K, Toba H, Kawakami Y, Yoshida M. [Malignant Pleural Mesothelioma Presenting Refractory Pneumothorax

Successfully Treated by Intrapleural Administration of Diluted Fibrin Glue;Report of a Case]. Kyobu Geka. 2017 May;70(5):393-396. Japanese. PMID: 28496089.

29. Mizumori Y, Nakahara Y, Kawamura T, Sasaki S, Tsukamoto H, Mochiduki Y. Intrabronchial Infusion of Autologous Blood Plus Thrombin for Intractable Pneumothorax After Bronchial Occlusion Using Silicon Spigots: A Case Series of 9 Patients With Emphysema. J Bronchology Interv Pulmonol. 2016 Jul;23(3):199-203. doi: 10.1097/LBR.0000000000000289. PMID: 27454474; PMCID: PMC4957960.
30. Tsukamoto T, Sasaki H, Nakamura H. Treatment of hemoptysis patients by thrombin and fibrinogen-thrombin infusion therapy using a fiberoptic bronchoscope. Chest. 1989 Sep;96(3):473-6. doi: 10.1378/chest.96.3.473. PMID: 2670463.
31. Claushuis TA, de Stoppelaar SF, Stroo I, Roelofs JJ, Ottenhoff R, van der Poll T, Van't Veer C. Thrombin contributes to protective immunity in pneumonia-derived sepsis via fibrin polymerization and platelet-neutrophil interactions. J Thromb Haemost. 2017 Apr;15(4):744-757. doi: 10.1111/jth.13625. Epub 2017 Feb 16. PMID: 28092405.
32. Bascarevic S, Ercegovac M, Hoda MA, Savic M, Vesovic R, Milenkovic V, Moromila M, Popovic M, Gompelmann D, Madzarevic P. Twenty four-month follow-up after bullectomy, unilateral and bilateral lung volume reduction surgery: a single-center retrospective analysis of consecutive cases. Eur J Med Res. 2024 May 10;29(1):279. doi: 10.1186/s40001-024-01879-4. PMID: 38725073; PMCID: PMC11083754.
33. Sohail H, Kilani Y, Osella J, Kamal ASF, Kumari B, Keftassa DE, Yusuf MH, Aldiabat M, Horoub A, Murthy S. Vanishing Lung Syndrome, or Idiopathic Giant Bullous Emphysema, with Pneumothorax, and Subcutaneous Emphysema in a 58-Year-Old Female Smoker with Chronic Obstructive Pulmonary Disease. Am J Case Rep. 2022 Dec 2;23:e938063. doi: 10.12659/AJCR.938063. PMID: 36457206; PMCID: PMC9724188.
34. Tanoğlu O, Gökgöz MB, Özmeriç A, Alemdaroğlu KB. Two-Stage Surgery for the Malleolar Fracture-Dislocation With Severe Soft Tissue Injuries Does Not Affect the Functional Results. J Foot Ankle Surg. 2019 Jul;58(4):702-705. doi: 10.1053/j.jfas.2018.11.033. Epub 2019 May 10. PMID: 31079983.
35. Noppen M, Tellings JC, Dekeukeleire T, Dieriks B, Hanon S, D'Haese J, Meysman M, Vincken W. Successful treatment of a giant emphysematous bulla by bronchoscopic placement of endobronchial valves. Chest. 2006 Nov;130(5):1563-5. doi: 10.1378/chest.130.5.1563. PMID: 17099038.
36. Im Y, Jeong BH, Park HY, Kim TS, Kim H. Expeditious Resolution of Giant Bullae with Endobronchial Valves and Percutaneous Catheter Insertion. Yonsei Med J. 2022 Feb;63(2):195-198. doi: 10.3349/ymj.2022.63.2.195. PMID: 35083906; PMCID: PMC8819409.
37. Welling JBA, Koster TD, Slebos DJ. From plugging air leaks to reducing lung volume: a review of the many uses of endobronchial valves. Expert Rev Med Devices. 2023 Jul-Dec;20(9):721-727. doi: 10.1080/17434440.2023.2233435. Epub 2023 Jul 7. PMID: 37409351.
38. Hetzel J, Boeckeler M, Lewis RA, Horger M, Haentschel M. Use of 3-D navigation to target the site of autologous blood installation for lung volume reduction in bullous emphysema. Chron Respir Dis. 2020 Jan-Dec;17:1479973120903556. doi: 10.1177/1479973120903556. PMID: 32053039; PMCID: PMC7019502.
39. Vedran U, Kavit A, Igor B, Damir K. Evolution of midface microvascular reconstruction: three decades of experience from a single institution. Eur Arch Otorhinolaryngol. 2022 Aug;279(8):4173-4180. doi: 10.1007/s00405-022-07321-x. Epub 2022 Mar 22. Erratum in: Eur Arch Otorhinolaryngol. 2026 Apr 29. doi: 10.1007/s00405-026-10038-w. PMID: 35316380.

40. Bhattacharyya P, Sarkar D, Nag S, Ghosh S, Roychoudhury S. Transbronchial decompression of emphysematous bullae: a new therapeutic approach. Eur Respir J. 2007 May;29(5):1003-6. doi: 10.1183/09031936.00030106. PMID: 17470621.
41. Cosgun T, Yardimci H, Tezel Ç. Bronchoscopic endobronchial valves. Breathe (Sheff). 2026 Mar 17;22(1):240249. doi: 10.1183/20734735.0249-2024. PMID: 41853060; PMCID: PMC12993746.
42. Egenod T, Guibert N, Ammar Y, Kessler R, Toublanc B, Favrolt N, Briault A, Dutau H, Wallyn F, Lachkar S, Cellerin L, Dusselier M, Vergnon JM. Endobronchial valves: 1st Multicenter retrospective study on the 2-step approach. Respir Med Res. 2023 Jun;83:100957. doi: 10.1016/j.resmer.2022.100957. Epub 2022 Oct 1. PMID: 36630778.
43. Omballi M, Noori Z, Alanis RV, Lukken Imel R, Kheir F. Chartis-guided Endobronchial Valves Placement for Persistent Air Leak. J Bronchology Interv Pulmonol. 2023 Oct 1;30(4):398-400. doi: 10.1097/LBR.0000000000000914. PMID: 36877223.
44. Taton O, Heinen V, Bondue B, Slebos DJ, Shah PL, Carron K, Moens O, Leduc D. Long-Term Follow-Up of Intralobar Bullae After Endobronchial Valve Treatment for Emphysema. Int J Chron Obstruct Pulmon Dis. 2022 Aug 2;17:1735-1742. doi: 10.2147/COPD.S363490. PMID: 35941900; PMCID: PMC9356607.
45. Brown MV, Badiei A, Jersmann H, Fon A, Chew CG, Lorraine B, Nguyen P. A 6-year experience of Zephyr endobronchial valves for severe emphysema in an Australian single-centre cohort. Intern Med J. 2024 Jun;54(6):871-881. doi: 10.1111/imj.16319. Epub 2024 Jan 22. PMID: 38247402.
46. Leppig JA, Song L, Voigt DC, Feldhaus FW, Ruwwe-Gloesenkamp C, Saccomanno J, Lassen-Schmidt BC, Neumann K, Leitner K, Hubner RH, Doellinger F. When Treatment of Pulmonary Emphysema with Endobronchial Valves Did Not Work: Evaluation of Quantitative CT Analysis and Pulmonary Function Tests Before and After Valve Explantation. Int J Chron Obstruct Pulmon Dis. 2022 Oct 11;17:2553-2566. doi: 10.2147/COPD.S367667. PMID: 36304970; PMCID: PMC9596192.
47. Zhang H, Duan CL, Xue GW, Xu WW, Ge CS, Cai YD, Zheng ZG, Du CL, Gao Y, Zhang JL, Li ZF, Zhang W, Wang L. [Effectiveness and safety of medical glue assisted argon plasma coagulation union giant emphysematous bulla volume reduction via thoracoscope on the treatment of spontaneous pneumothorax with subpleural bullae]. Zhonghua Jie He He Hu Xi Za Zhi. 2022 Dec 12;45(12):1204-1208. Chinese. doi: 10.3760/cma.j.cn112147-20221014-00820. PMID: 36480851.
48. Riveiro-Blanco V, Pou-Álvarez C, Ferreiro L, Toubes ME, Quiroga-Martínez J, Suárez-Antelo J, García-Prim JM, Rivo-Vázquez JE, Castro-Calvo R, González-Barcala FJ, Gude F, Valdés L. Recurrence of primary spontaneous pneumothorax: Associated factors. Pulmonology. 2022 Jul-Aug;28(4):276-283. doi: 10.1016/j.pulmoe.2020.06.003. Epub 2020 Jun 26. PMID: 32601016.
49. Chan IYH, Philip KEJ, Tsitsias T, Reynolds C. Spontaneous resolution of a giant bulla in a patient presenting with COVID-19 with presumed superadded bacterial infection. Respirol Case Rep. 2024 Dec 3;12(12):e70074. doi: 10.1002/rcr2.70074. PMID: 39629259; PMCID: PMC11613095.
50. Taniguchi J, Aso S, Taisuke J, Matsui H, Fushimi K, Yasunaga H. Endobronchial silicone spigot in prolonged air leaks: Nationwide study on outcomes and risk factors for treatment failure. Respir Investig. 2024 May;62(3):449-454. doi: 10.1016/j.resinv.2024.03.004. Epub 2024 Mar 23. PMID: 38522361.

Figures

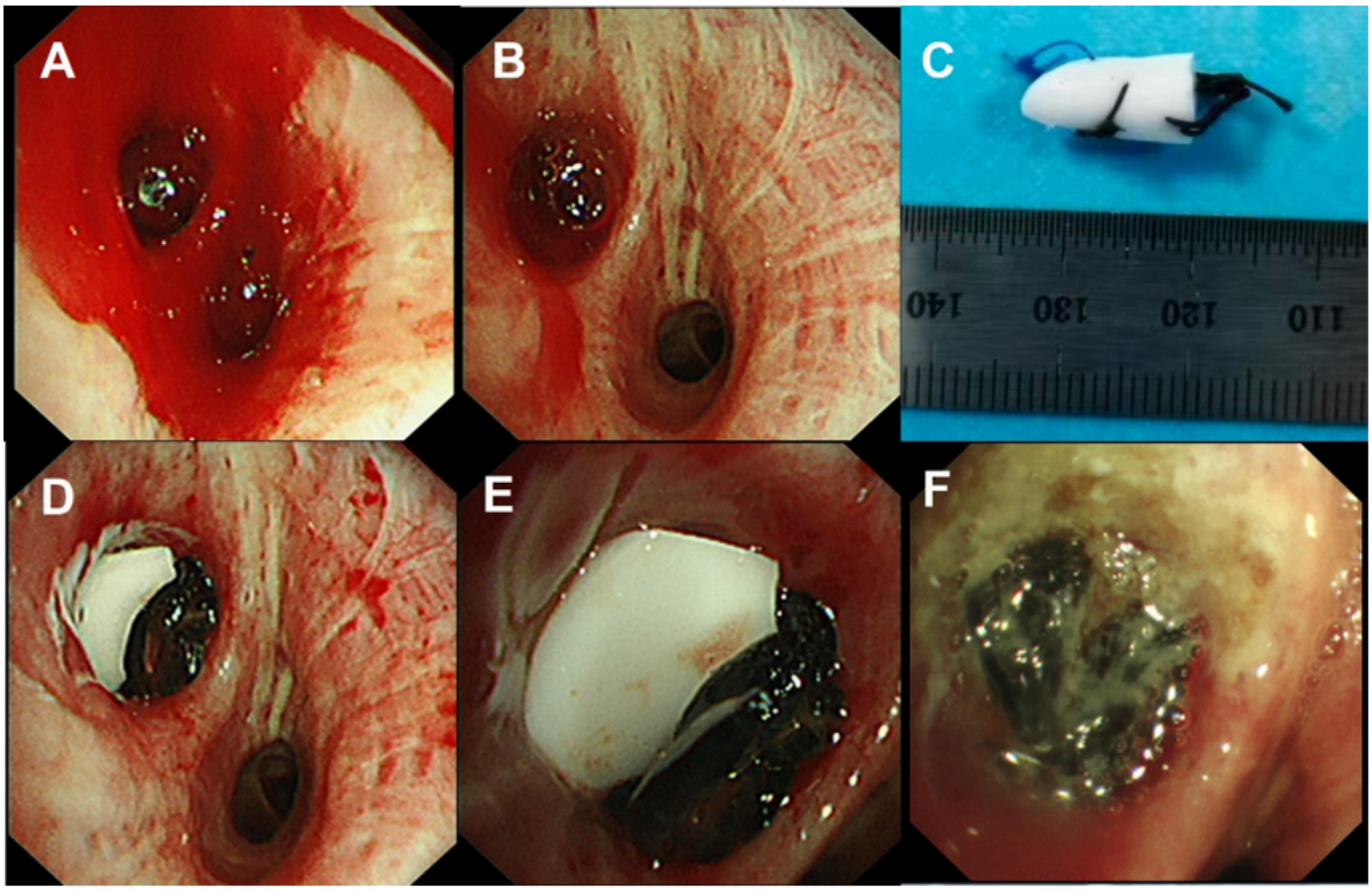


Figure 1

Bronchoscopic prosthesis placement and follow-up

A: Preoperative bronchoscopic view showing active bleeding in the dorsal segment of the left lower lobe with fresh blood stains attached to the airway wall.

B: Further localization confirming that the bleeding originated mainly from the bronchial orifice of the dorsal segment of the left lower lobe.

C: Physical view of the custom-made sutured silicone occlusion prosthesis. The prosthesis is conical in shape with anti-slip sutures in the middle section and a traction loop at the tail for easy clamping and placement under endoscopy.

D: Intraoperative bronchoscopic placement of the prosthesis, which was pushed and anchored into the bronchus of the dorsal segment of the left lower lobe.

E: Immediate bronchoscopic view after prosthesis implantation. The prosthesis was in place, the bronchus of the dorsal segment of the left lower lobe was completely occluded, and no active bleeding was observed.

F: Bronchoscopic re-examination at 6 months postoperatively. The prosthesis remained in position. No obvious mucosal congestion, erosion or granulation hyperplasia, recurrent bleeding or secretion retention was found in

the airway.

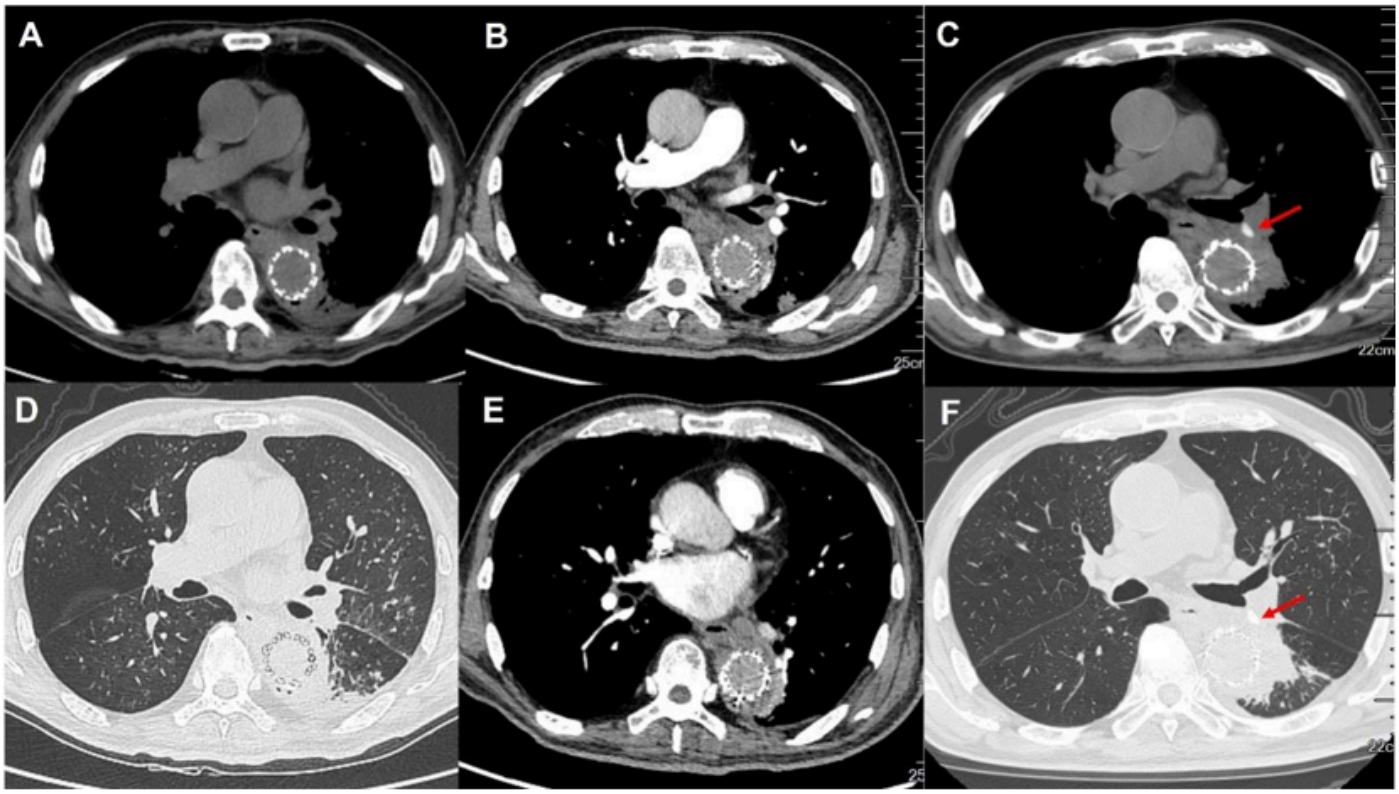


Figure 2

Chest CT before and after prosthesis placement

A: Preoperative plain chest CT scan showing bleeding lesions in the dorsal segment of the left lower lobe with exudative changes in the surrounding lung tissue.

B: Preoperative contrast-enhanced chest CT clearly demonstrating the target bleeding bronchus and adjacent vascular anatomy to guide precise prosthesis placement.

C: Chest CT re-examination (mediastinal window) at 6 months after surgery. The red arrow indicates the properly positioned artificial occlusion prosthesis. The original bleeding lesions were significantly absorbed, with no abnormal enhancement or signs of recurrence.

D: Preoperative plain chest CT scan (lung window) presenting bleeding lesions and associated parenchymal changes in the dorsal segment of the left lower lobe.

E: Preoperative contrast-enhanced chest CT (lung window) further illustrating the relationship between bleeding lesions and surrounding blood vessels.

F: Chest CT re-examination (lung window) at 6 months after surgery. The red arrow marks the artificial prosthesis in situ. Perilesional exudation was completely resolved. No atelectasis or obstructive pneumonia was observed, and the pulmonary ventilation remained satisfactory.