LITERATURE REVIEW

Bronchial Artery Embolization in Hemoptysis

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ABSTRACT

Hemoptysis, characterized by bleeding from the lower airways, is classified as mild, moderate, or massive, with massive hemoptysis carrying a mortality rate of 6.5–38%. Tuberculosis (TB) remains the most common cause globally. Management strategies include invasive and noninvasive options, with bronchial artery embolization (BAE) emerging as a cornerstone of noninvasive treatment since its introduction in the 1970s. Bronchial artery embolization provides rapid bleeding control and high success rates for both short- and long-term outcomes. Despite these advantages, recurrence rates range widely from 10–55%, often due to incomplete embolization, vessel recanalization, and collateral vessel development. The procedure employs embolic agents such as polyvinyl alcohol (PVA) particles, gelatin sponges, and tris-acryl gelatin microspheres, with minimal complications such as spinal cord infarction or broncho-esophageal fistulas. Diagnostic tools like computed tomography (CT) and bronchoscopy complement BAE by localizing the bleeding sites, stabilizing the airway, and aiding in definitive management. Bronchoscopy serves diagnostic and therapeutic purposes, employing techniques such as vasoconstrictor instillation, laser therapy, and balloon tamponade to control bleeding. Bronchial artery embolization is particularly effective for patients with life-threatening or recurrent hemoptysis who are unsuitable for surgery, often acting as a bridge to elective interventions. This literature review highlighted the pathophysiology, diagnostic modalities, BAE techniques, outcomes, and challenges involved in managing hemoptysis, emphasizing the role of BAE as a vital, minimally invasive therapeutic option.

INTRODUCTION

The expectoration of blood or mixed with mucus originating from the lower airway can be defined as hemoptysis.[1] Massive hemoptysis is the expectoration of 300-600 mL of blood from the lower airway within 24 hours. It is considered to be a life-threatening state with mortality ranging from 6.5 to 38%.[2] Etiologies of massive hemoptysis include cryptogenic hemoptysis, lung cancer, necrotizing pneumonia, tuberculosis (TB), and bronchiectasis.[2]

The most common cause of hemoptysis worldwide to date is TB infection, both cavitary and non-cavitary. A French study showed that in patients with hemoptysis, 25% had underlying TB disease and 6% had aspergillosis.[3] The primary source of bleeding is predominantly the bronchial arteries, accounting for approximately 90%, while the remaining bleeding originates from the pulmonary arteries, the aorta, and other arterial systems.[2,4] Massive or recurrent hemoptysis management is stratified into invasive and non-invasive modalities.[5]

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In the last three decades, embolization has been acknowledged as the safest and most effective non-operative procedure for managing massive or recurrent hemoptysis. It has become an option in life-threatening hemoptysis.[6] In 1973, Remy, *et al*. introduced the procedure for the first time.[5] The majority of massive hemoptysis patients are not eligible for surgery due to inadequate pulmonary function and comorbidities. For some conditions, such as aspergilloma, hydatidiform cysts, and tumors, surgery remains an option, especially when hemoptysis does not improve with other types of management. Bronchial artery embolization (BAE) remains effective in helping to prepare for elective surgery.[7]

Bronchial artery embolization is known as the most effective minimally invasive option for patients with massive or recurrent hemoptysis who are not eligible for surgery. The embolization material typically includes polyvinyl alcohol (PVA) and gelatin foam particles. Several factors affect the long-term success of BAE, including incomplete embolization, recanalization of the bleeding vessels, revascularization of collateral circulation, and the progression of the underlying pulmonary disease.[8]

Complications of BAE are rare, but there are postoperative complications such as chest pain, fever, allergic response, and severe spinal cord injury caused by spinal artery occlusion.[9] The success rate and bleeding control using BAE is relatively high, but the hemoptysis recurrence rate is also reported to vary around 10-55%.[2]

HEMOPTYSIS

Definition

Hemoptysis is bleeding originating from the lower airway, which can be divided into mild (50 mL/day), moderate (50-300 mL/day), and massive.[10] Massive hemoptysis is expectoration from the lower airway with a total production within 24 hours of 300-600 mL of blood.[2,11] The mortality of untreated massive hemoptysis can be more than 50%.[2] Respiratory distress resulting from massive hemoptysis is attributed not only to the volume of bleeding but also to pre-existing comorbidities. Tuberculosis (TB) infection is the leading cause of massive hemoptysis, followed by other pulmonary conditions, including lung cancer, bronchiectasis, cystic fibrosis, lung abscess, and trauma.[2] Most hemoptysis bleeding sources originate from the bronchial arteries.[4,11] The primary goals in hemoptysis are to control the bleeding, prevent aspiration, and address the underlying cause.[12] Table 1 summarizes the etiologies that cause hemoptysis.[13]

Table 1. The etiology of hemoptysis[13]

Etiology of Hemoptysis	
Pulmonary origin	Cystic fibrosis
	Tuberculosis
	Aspergillosis
	Nontuberculous mycobacterium
	Pneumonia
	Lung abscess
	Pneumoconiasis
	Bronchogenic carcinoma
	Infiltrating mass
	Fistula from bronchovascular
	Bronchiectasis
Cardiovascular origin	Mitral stenosis
	Bronchial artery aneurysm
	Pulmonary embolization
	Pulmonary arterial hypertension
	Rupture of a thoracic artery aneurysm
	Aortobronchial fistula
	Congestive heart failure
	Vascular malformation
Others	Trauma
	Coagulopathy
	Iatrogenic
	Foreign body
	Drugs and toxins

Pathophysiology of hemoptysis

Most bleeding sources arise from the bronchial arteries, typically due to neovascularization caused by inflammatory conditions. Several factors, such as local hypoxia and decreased pulmonary artery perfusion, influence this state. In chronic inflammatory conditions, the release of angiogenic growth factors in large quantities that support the growth process and neovascularization of the bronchial arteries leads to a higher risk of bleeding.[13] The fragility of the bronchial and pulmonary artery walls occurs when granulated connective tissue replaces the tunica media and adventitia. Over time, this tissue is replaced by a fibrin layer, leading to erosion of the arterial wall and the formation of a pseudoaneurysm. As this progresses, nutritional intake becomes impaired, triggering hypoxic vasoconstriction, intravascular thrombosis, and edematous compression. This condition potentially creates a higher risk of vessel rupture, leading to massive hemoptysis.[14]

Hemoptysis results from two circumstances that raise the bronchial artery passage. Increased bronchial artery flow results in conditions that cause diminished pulmonary blood flow, such as thromboembolic disorder and Takayasu arteritis. Pulmonary bronchial artery anastomoses normally vasodilate to accommodate increased systemic blood flow to the lungs. These anastomoses are more likely to rupture as they are finer and under systemic blood pressure. The bronchial artery flow can also increase in lung inflammatory conditions like bronchiectasis and TB infection. Obstruction and inflammatory conditions involve angiogenic growth factors that increase the collateral and neovascular supply. These collateral vessels are more likely to rupture.[5,11]

Diagnosis of hemoptysis

The primary goal in diagnosing hemoptysis is to identify the bleeding site and its cause. Computed tomography (CT) and bronchoscopy are accurate techniques for this purpose. Bronchoscopy is especially effective within 48 hours of hemoptysis and is ideal for patients with moderate or massive bleeding. Computed tomography angiography (CTA) is a non-invasive, comprehensive method that detects the primary source of hemoptysis, localizes active bleeding, and aids in surgical or embolization planning. Additionally, CTA can pinpoint the exact location and variations of the bronchial arteries. Bronchoscopy, with a sensitivity of 73-93% for detecting bleeding sites and 2.5-8% for identifying the cause of hemoptysis, is vital for diagnosis and therapy and can help obtain examination samples.[5] Bronchoscopy plays a dual role in diagnosing and managing hemoptysis, particularly in life-threatening cases. Walker, *et al*. (2015) emphasized its utility in localizing bleeding sources, while Li, *et al.* (2023) highlighted its therapeutic potential using techniques like argon plasma coagulation and vasoconstrictor instillation.[2,11]

After the initial assessment, it is crucial to determine if the patient's life is at risk. The primary goal is to locate and identify the cause of the bleeding. The patient's history of hemoptysis, including frequency and recurrence, as well as any history of malignancy, heart disease, vasculitis, coagulation disorders, and anticoagulant use, should be thoroughly reviewed. Supporting examinations include laboratory tests for coagulation parameters, platelet count, and coagulation status. Imaging studies such as thoracic X-rays, contrast-enhanced CT scans, and CTA should be performed. If the CT scan cannot determine the cause, bronchoscopy is recommended. Digital subtraction angiography is no longer the primary diagnostic tool, as it is less effective than multislice CT (MSCT) in detecting bronchial and non-bronchial arteries. Table 2 summarizes the diagnostic methods and the information they provide.[1]

Table 2. Diagnostic methods and the yield they provide[1]

Methods	Analysis Results	Information
Clinical chemistry examination	Primary: inflammatory parameters, differential count, coagulation status Secondary: autoimmune diagnosis	Depending on the cause
Important parameters (with or without blood gas analysis)	Gas exchange and hemodynamics	Depending on the cause
Chest X-ray	Localization of the source and cause of bleeding (pneumonia, lung abscess, lung cancer, tuberculosis)	Ability to determine the side: 33-82% Ability to determine cause: 35-50%
Multislice computed tomography with angiography	Localize the source and cause of bleeding based on vascular anatomy and origin	Ability to determine the side: 63-100% Ability to determine the cause: 60-77%
Bronchoscopy	Localization of bleeding (right/left lung, lobe/segment), cause of bleeding, sample collection for examination, management to keep the airway free of blood, administration of vasoconstrictors, tampons, laser, and argon plasma coagulation	Ability to determine the side: 73-93% Ability to determine cause: 2.5-8%

Management of massive hemoptysis

The main goal of massive hemoptysis treatment is to control and stop the bleeding. The initial approach to managing mild or moderate hemoptysis involves conservative treatment by addressing the underlying condition.[1] Early stabilization and airway management are crucial in cases of massive hemoptysis. The initial treatment should prioritize securing the airway, providing fluid resuscitation if necessary, and treating the underlying condition. Measures such as positioning the patient to prevent aspiration can be taken if the source of bleeding is known, before placing the patient in the lateral decubitus position with the position of the bleeding source below. A previous study suggested that the intravenous or nebulized administration of tranexamic acid can reduce the volume of hemoptysis.[8]

Intubation is necessary for airway management in cases of life-threatening hemoptysis. Single-lumen endotracheal intubation with a minimum size of 8 can be performed, and unilateral intubation of one of the main bronchi can help protect the non-bleeding contralateral lung. Although it cannot be passed through the bronchoscope to intervene, it can help oxygenate and ventilate effectively while waiting for definitive management. Using a double-lumen tube for intubation allows single-lung ventilation while simultaneously isolating the bleeding area.[8]

Additionally, flexible fiberoptic bronchoscopy can assist in clearing the airway and ensuring proper ventilation. Therapeutic bronchoscopy can also be performed for hemostatic purposes. Therapeutic techniques are used to stop bleeding, such as giving rinses with cold saline, local instillation using vasoconstrictor agents, and balloon blockers. More specialized techniques can also be provided, such as a local laser using neodymium-doped yttrium aluminum garnet (Nd:YAG) or argon plasma coagulation for hemostasis, endobronchial stents with tampons, balloon tampons, and topical cellulose mesh.[8]

Bronchoscopy helps diagnose and treat hemoptysis and can be performed with either a flexible or rigid instrument. It effectively localizes the bleeding source (with a sensitivity of 73 to 93%), whether within the bronchoscopically visualized area or beyond.[1] Rigid bronchoscopy is safer and more effective than flexible fiberoptic bronchoscopy for managing life-threatening hemoptysis. It can suction blood clots better. Therefore, airway visualization can be improved. Specialized treatments such as argon plasma coagulation, electrocautery, and laser can also be performed using rigid bronchoscopy to control bleeding.[8]

Bronchial artery embolization for hemoptysis caused by malignancy is more likely to be followed by a bronchoscopy evaluation. These bronchoscopies are conducted primarily for diagnostic purposes and/or to remove blood clots and secretions rather than for the further therapeutic management of active hemoptysis.[15] Detecting and locally treating bleeding sources within the central airways is also reliable. For peripheral lung bleeding, bronchoscopy helps in approximately localizing the source (right or left lung, lobe, segment) to assist in planning further treatment (such as BAE or surgery) and for tissue sampling (for microbiological, cytological, or histological analysis).[1]

Angiography has both diagnostic and therapeutic potential. Once the general condition is stabilized, BAE is the main option in massive hemoptysis.[8] The BAE procedure should be performed immediately after the CT scan and bronchoscopy results. The primary goal of BAE is to lower the perfusion pressure in the bronchial arteries of the affected area to stop the bleeding. Surgical management is an option in bleeding caused by traumatic or iatrogenic lung damage and in cases of unsuccessful BAE, as summarized in Figure 1. It is important to note that patients with chronic lung disease may struggle to tolerate supination, leading to possible interruptions in the BAE procedure due to coughing up blood. Ensuring adequate oxygenation during the procedure is essential.[1]

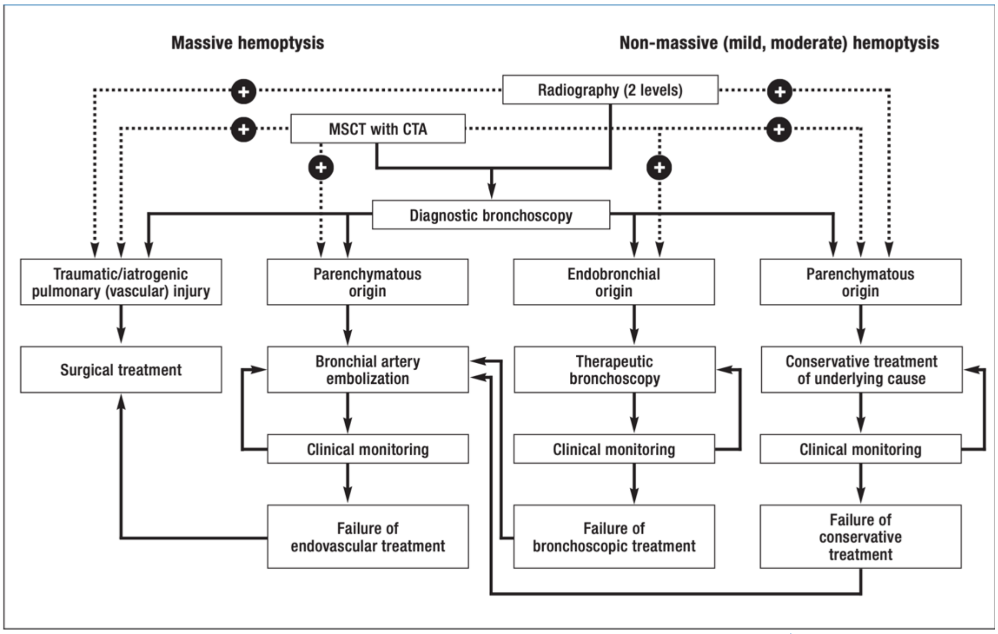

Figure 1. Flow of diagnosis and management of hemoptysis[1]

Table 3. Treatment options for hemoptysis[1,16]

	Bronchial Artery Embolization	Bronchoscopy	Surgery	Conservative
Aim	Reduce systemic arterial perfusion pressure in the bronchial arteries of the affected region to achieve hemostasis	Ensuring adequate gas exchange by clearing the airways of blood and maintaining their patency	Planned as an elective procedure following multidisciplinary hemostatic management	Control mild or moderate hemoptysis
Advantages	Minimally invasive, high technical success rate	Acts both as a therapeutic and diagnostic tool	Curative procedure, excellent long-term results	Optimization of coagulation status
Disadvantages	Recurrence rate may vary	Restricted to addressing bleeding that originates within the endobronchial area	High mortality rate	Recurrence rate may vary

BRONCHIAL ARTERY EMBOLIZATION IN HEMOPTYSIS

Definition and history of bronchial artery embolization

Bronchial artery embolization has been used to manage both massive and recurrent hemoptysis. It is also effective in preparing patients for elective surgery.[7] This procedure, first introduced by Remy, *et al*. in 1973-1974, is now regarded as the primary method for quickly controlling bleeding in cases of massive hemoptysis.[2,15] The recurrence of hemoptysis following BAE varies widely, with rates reported between 10% and 55% depending on factors such as incomplete embolization, recanalization of vessels, and collateral vessel development.[2]

For instance, Li, *et al*. (2023) identified risk factors such as underlying pulmonary diseases and comorbidities, while Pei, *et al*. (2014) highlighted differences in recurrence rates between patients with active vs. inactive TB.[2,17] These findings underscore the importance of addressing underlying conditions to improve long-term outcomes.[2,17] Surgery was initially the definitive therapy to manage hemoptysis up to the 1980s, but surgical intervention has a mortality of up to 18% when performed electively.[18] This increases to 40% when performed immediately.[18] In a recent study, mortality has remained at 19%.[18]

Bronchial artery embolization has become the safest and most effective non-surgical intervention for recurrent or massive hemoptysis.[1] Due to its safety and effectiveness, it has largely replaced emergent surgery for managing life-threatening hemoptysis. Emergent lung resections have high mortality rates, with studies showing a 35-40% mortality rate for emergency surgeries compared to significantly lower rates (0-18%) for elective procedures.[8] An emergent surgical intervention is now reserved for cases such as traumatic chest injuries, iatrogenic pulmonary artery rupture, or pulmonary artery hemorrhage in resectable lung tumors.[8] Surgery is strongly indicated for bleeding caused by necrotizing tumors, cavernous TB, and refractory aspergilloma, particularly when BAE has failed, as well as in specific conditions such as traumatic or iatrogenic causes of pulmonary vascular injuries.[1]

Anatomy of bronchial arteries

The lungs receive blood from two vascular systems, specifically the bronchial and pulmonary arteries. Pulmonary arteries transport low-oxygen blood at low pressure, accounting for 99% of lung blood flow and facilitating gas exchange at the alveolar-capillary membrane. In contrast, bronchial arteries, which branch from the proximal descending thoracic aorta, carry oxygen-rich blood at a pressure six times higher than the pulmonary arteries. Bronchial arteries are termed orthotopic if they originate between the superior endplate of the T5 vertebra and the inferior endplate of the T6 vertebra. Meanwhile, those originating from other locations are classified as ectopic (Figure 2). In about 64% of hemoptysis cases, the bleeding source is the orthotopic bronchial artery, while in 36% of cases, the source is the ectopic bronchial artery.[11,19]

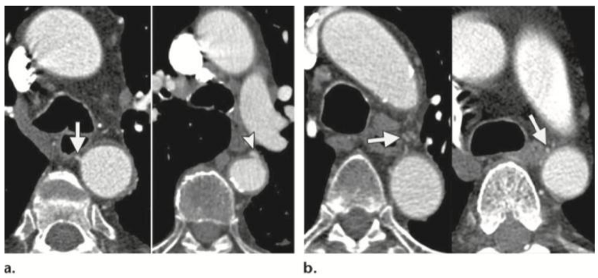

Figure 2. a) Axial computed tomography angiography (CTA) revealing the right orthotopic bronchial artery (indicated by the arrow) originating from the anteromedial wall of the thoracic aorta and the left orthotopic bronchial artery (marked by the arrowhead) originating from the anterior wall of the thoracic aorta; b) Axial CTA displaying normal bronchial arteries (indicated by arrows) as small or linear nodules with a diameter of less than 2 mm to help clarify mediastinal structures[11]

In 90% of massive hemoptysis cases, the bleeding source is the bronchial circulation, while the remaining 10% comes from the pulmonary and systemic arterial circulations. The bronchial circulation, which is subjected to higher systemic pressure from the descending aorta, particularly between the T5 and T6 vertebrae, supplies blood to the esophagus, trachea, pericardium, hilum node, and visceral pleura. Four anatomical variations are common in humans, with three types being the most prevalent (Figure 3). Type 1 (40%) features two blood vessels on the left and one on the right, forming an intercostobronchial trunk (ICBT). Type 2 (21%) has one blood vessel on the left and one ICBT on the right. Type 3 (20%) includes two blood vessels on the left and two on the right (the ICBT and the bronchial artery). Type 4-9 (9.7%) is another variation with up to four arteries on the right and left sides.[11]

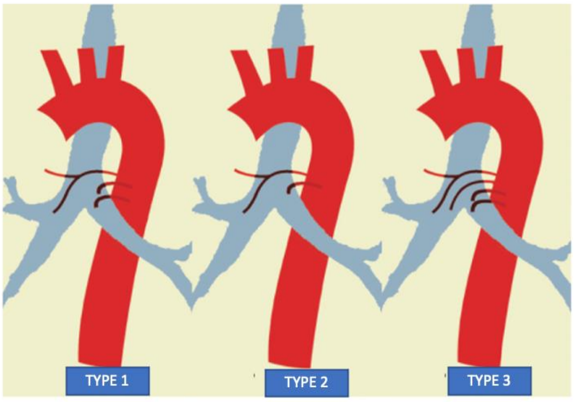

Figure 3. Anatomy of three types of bronchial artery variations[11]

Indications for bronchial artery embolization

The worldwide known indications for BAE are for TB and post-TB infection. Benign conditions such as cystic fibrosis, bronchiectasis, sarcoidosis, and chronic obstructive pulmonary disease (COPD) are frequently found as indications for BAE in the United States (US). In the US, patients with lung cancer account for about 25% of hemoptysis cases, and this group has a high mortality rate if not properly managed.[15] No literature indicates a significant difference in bleeding volume between patients with hemoptysis due to malignancy and those with non-malignant causes.[15]

Treating even small amounts as potentially life-threatening until proven otherwise is essential when addressing hemoptysis. The assessment starts with evaluating the patient's overall condition and distinguishing between hemoptysis and pseudo-hemoptysis. A portable X-ray can be performed to help diagnose the underlying etiology of the hemoptysis. These preliminary investigations help determine the severity of the hemoptysis to further guide appropriate treatment. In cases of massive or life-threatening hemoptysis, the focus is on acute stabilization and pinpointing the source of the bleeding. Once stabilized, a CT scan can be performed. Non-massive hemoptysis is generally managed conservatively.[13]

Contraindications of arterial embolization

Contraindications for BAE are similar to those for general angiography, including uncorrected coagulopathy, renal failure, and severe contrast allergy. In cases of life-threatening hemoptysis, it is crucial to medically stabilize the patient by ensuring airway protection, optimizing oxygenation, providing hemodynamic support, and correcting any coagulopathy. Maneuvers that protect the airway are important to perform before and during the BAE procedure, as there is a risk of asphyxia. These measures include positioning the bleeding side downward to prevent blood from spilling into the opposite lung, selectively intubating the unaffected lung, using a double-lumen tube to ventilate each lung separately, and performing an endobronchial tamponade with a Fogarty catheter. Additionally, topical hemostasis can be achieved through bronchoscopy.[17]

Bronchial artery embolization technique

The majority of hemoptysis cases treated with BAE have good clinical outcomes that are significant.[11] Multidetector CT with reformed volumetric imaging is helpful in patients with hemoptysis before pre-embolization, as it can identify dilated bronchial arteries and the source of the bleeding.[11,12] Imaging examinations are fast and provide vascular mapping for the interventionalist before performing the procedure. In a comparative study with a population of 200 samples, CT before angiography reduced the catheterization failure rate and the number of patients requiring surgical intervention.[11] Administering moderate sedation and anxiolytics to the patient can ease the process of bronchial artery embolization. Nevertheless, ensuring that respiratory function, responsiveness, and communication abilities are not compromised is crucial.[6]

During the 1980s and 1990s, surgical gelatin sponges (Gelfoam) were commonly used because they were inexpensive and simple to apply. However, they frequently resulted in only temporary occlusion due to their tendency to be absorbed.[6] Recently, BAE has usually used PVA particles, gelatin sponges, and tris-acryl gelatin microspheres. The outcomes of the different agents showed comparable results. A study by Lee, *et al*. (2022) between 2004 and 2019 had a population of 122 hemoptysis patients who underwent BAE procedures using N-butyl cyanoacrylate (NBCA) material and had good outcomes.[20]

Under sterile conditions and after administering local anesthesia to one groin, a 5-French (F) vascular sheath is inserted through a transfemoral access route. A suitable 4F or 5F catheter (such as a pigtail catheter) is positioned in the proximal descending aorta to obtain chest view images via digital subtraction angiography (DSA) with a mechanical injection of a contrast agent (iodine-based, with an injection volume of 30 mL at a flow rate of 20 mL/sec). Multiple projections, including anterior-posterior, left anterior oblique (LAO), and right anterior oblique (RAO), should be acquired to systematically visualize the bronchial artery outflow tract from the aorta. Following the Seldinger technique and using a 0.035 guide wire, the ostia of all bronchial arteries are located with appropriate 4F or 5F catheters (Cobra, Mikaelsson, Simmons, Shepherd Hook, Headhunter, Sidewinder, or SOS Omni) and visualized using selective DSA with manual injection of approximately 5-6 mL of contrast agent.[6] An example of embolization in a 62-year-old patient is shown in Figure 4.[2]

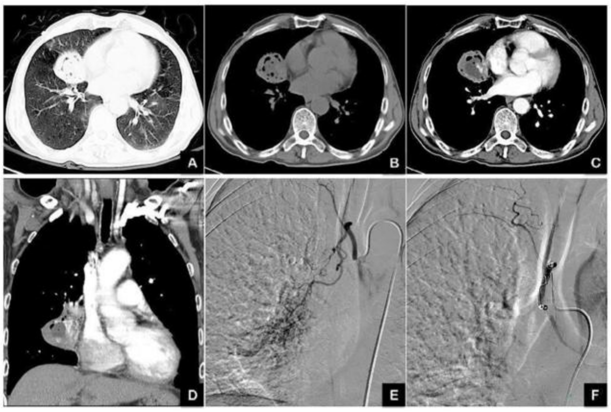

Figure 4. A) High-resolution chest computed tomography (HRCT) and digital subtraction angiogram images before and after bronchial artery embolization in a 62-year-old male patient with a 30-year history of intermittent hemoptysis, which worsened over the past month, producing approximately 150 mL of blood each time; B-D) HRCT images revealed a reduction in volume and uneven density in the right middle lobe, along with cavities and necrosis; E) Digital subtraction angiogram (DSA) following selective catheterization of the right bronchial artery and super-selective catheterization with a microcatheter shows a hypertrophied artery and hypervascularity in the right middle lobe; F) Post-embolization DSA displayed no residual blood flow to the lesion[2]

The use of metal-based coils can achieve relatively proximal blockages. Coils are effective for actively bleeding vessels, such as those in pseudoaneurysms and large systemic-to-pulmonary shunts. However, in cases of recurrent bronchial artery hemoptysis, this can hinder reintervention in the peripheral areas of the bronchial artery (such as repeated particle embolization) if there is reconstitution and perfusion of the pulmonary artery vascular bed through mediastinal or bronchial collaterals. Pulmonary arteriovenous malformations (PAVMs) should be treated using targeted, removable stainless steel embolization coils or balloons, similar to the treatment of Rasmussen aneurysms, where the feeding pulmonary arteries are sealed off.[6,7] Figure 5 shows a case where a coil was successfully used to stop bleeding.[6]

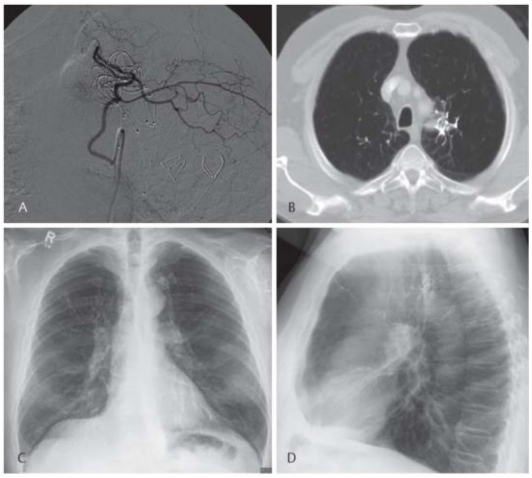

Figure 5. Hemoptysis following the treatment of upper lung lobe pulmonary emphysema with endobronchial coils, showing areas of hypervascularization in the left paramediastinal upper lobe. A) Digital subtraction angiography of the left truncus intercostobronchialis; B) Contrast-enhanced computed tomography; C) Overview of chest X-ray in the posteroanterior view; D) Lateral projection[6]

Outcome of bronchial artery embolization

Outcomes of BAE can vary. A study conducted in Mexico, as cited by Li, *et al*. (2023), which assessed patients at 24 hours, 30 days, 120 days, and 180 days after BAE, found that bleeding was the cause of death for 3 out of 24 patients within 24 hours.[2] Surgical resection was necessary for 4 out of 16 patients who did not have recurrent hemoptysis within 180 days.[2] The survival rates for the 24 patients were 75% at 30 days and 67% at 180 days.[2] Meanwhile, a study from India, as cited by Li, *et al*. (2023), with a population of hemoptysis in former TB patients showed that 91% of cases had rapid bleeding control immediately after BAE, and that hemoptysis recurrence within 3 months was found to be only 6% and 3.5% within 6 months.[2]

A study conducted by Pei, *et al*. (2014) in China on a TB-induced hemoptysis population showed that BAE action could control bleeding in 14 days up to 86.6% and 75.9% in 360 days.[17] Patients with active pulmonary TB status had a significantly lower hemoptysis recurrence rate than those with inactive pulmonary TB (p=0.04), as confirmed by the Cox regression hazards model (p=0.046) shown in Figure 6.[17] The complications reported in this study reached 30%, but all were minor complications.[17] The study did not include major complications, such as spinal cord infarction.[17] Further research that lasted for 10 years in Thailand by Dorji, *et al*. (2021) showed a technical success rate in stopping life-threatening hemoptysis up to 92.4% and clinical success of 70.1%.[21] The study also reported that 5.4% of cases experienced minor complications, the majority of which were post-embolization syndrome and hematomas in the groin area.[21] Complications in the form of spinal cord infarct were found to be 1.4-6.5%.[21]

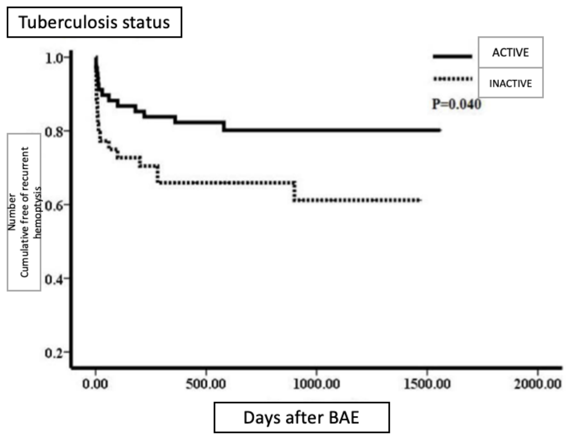

Figure 6. The Cox regression hazards model showed that patients with active pulmonary tuberculosis (TB) status had significantly lower hemoptysis recurrence rates compared to inactive pulmonary TB[17]

Many case reports highlight the effectiveness of BAE in benign cases, but few studies have examined BAE in oncology cases. Witt, *et al.* (2000), as cited by Han, *et al.* (2019), conducted a prospective study involving 30 patients with bronchial malignancies treated with platinum coils.[22] The study achieved a 63% response rate and observed more prolonged survival in the group that underwent BAE.[22] Park, *et al.* (2007), as cited by Han, *et al.* (2019), reported a 79% partial resolution rate 30 days post-BAE in 19 malignancy cases with hemoptysis.[22] Wang, *et al.* (2009), as cited by Han, *et al.* (2019), showed a success rate of up to 89%, higher than previous studies.[22] Han, *et al.* (2019) reported a 98% technical success rate and 82.1% clinical success rate.[22] The comparison of the aforementioned BAE results is summarized in Table 3. The studies from Zhang (1994) to Bhalla et al. (2015) were all in oncology cases, while the rest are a mix of oncology and infectious cases.

Table 4. Comparison of bronchial artery embolization results[7,23]

Research and Years	Total Patients	Technical Success Rate (%)	Grade of Hemoptysis (%)	Recurrence Rate (%)
Zhang (1994)	35	91.4	Massive = 100	20
Lee, *et al*. (2008)	70	99	Massive = 59 Mild to moderate = 41	36
Poyani, *et al*. (2000)	140	98.5	Massive = 69 Mild to moderate = 31	10
Woo, *et al*. (2013)	406	94	Massive 100	-
Bhalla, *et al*. (2015)	334	92	Massive = 21 Mild to moderate = 79	14
Shimohira, *et al*. (2015)	12	100	Not reported	17
Mehta, *et al*. (2015)	26	77	Not reported	12
Miyano, *et al*. (2016)	27	93	Not reported	7
Kucukay, *et al*. (2018)	174	100	Not reported	Not reported
Lee, *et al*. (2019)	33	100	Not reported	24
Shimohira, *et al*. (2019)	52	100	Not reported	33

Complications of bronchial artery embolization

Complications associated with BAE are rare but noteworthy. Dorji, *et al.* observed minor complications like post-embolization syndrome in 5.4% of cases.[21] Posterior circulatory stroke has symptoms such as vertigo, dysphagia, and cortical blindness, and can occur shortly after BAE treatment. This posterior circulatory stroke hits several areas, such as the cerebellum and brainstem.[4,10] The worst complication of BAE is spinal cord ischemia resulting from accidental embolization of the anterior or posterior spinal arteries. A previous study reported that the risk of this complication ranges from 1.4% to 6.5%.[13] These complications can be avoided using a particular catheterization, opting for larger particle sizes, directly visualizing under fluoroscopy, and carefully using iodinated contrast media.[3]

SUMMARY

Hemoptysis is the expectation of blood mixed with mucus from the lower airways. It is divided into mild, moderate, and massive, with massive hemoptysis being a life-threatening condition. Hemoptysis therapy is divided into noninvasive and invasive, with BAE as one of the minimally invasive management options. Bronchoscopy has a diagnostic and therapeutic role. Bronchial artery embolization is the most effective minimally invasive alternative measure in massive and recurrent hemoptysis cases, with varying outcomes.

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Conflict of Interest
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Conceptualization, literature search, writing original draft preparation: DPA. Supervision: FI, DS, AD. Validation: FI, AD. Methodology support: DS. Review: DS, AD, BRA. All authors contributed and approved the final version of the manuscript.

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