Bronchial Artery Embolization
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Massive hemoptysis is a life-threatening emergency. Chest radiograph, computed tomography, and bronchoscopy play a complementary role in diagnosing the underlying cause of hemorrhage and localizing the bleeding site. Bronchial artery embolization remains the primary and most effective method in controlling massive hemoptysis. Bronchial and nonbronchial systemic arteries are the main source of bleeding and are embolized with polyvinyl alcohol particles or gelatin sponge. Immediate cessation of bleeding occurs in more than 75% of patients; however, long-term recurrences are common in patients with progressive lung disease. Complications are infrequent except for a rare occurrence of spinal cord ischemia.

KEYWORDS bronchial arteries, hemoptysis, intercostal arteries, transcatheter embolization

Hemoptysis may present as an acute medical emergency, for which a vascular interventionalist may be called on for angiographic evaluation and therapeutic intervention. Hemoptysis refers to the expectoration of blood that originates from the respiratory tract. Although the exact definition of massive hemoptysis varies widely, a blood loss totaling 300-600 mL over a 24-hour period is considered massive.1 Recurrent small amounts of hemoptysis are also considered significant if the blood loss exceeds 100 mL/d over 3 days in a week. However, any amount of hemoptysis is clinically significant if it compromises the airway and/or ventilation of both of the lungs. Thus, active intervention is indicated, irrespective of hemodynamic stability, if imminent or potential airway compromise is suspected in the presence of hemoptysis.

Causes

The causes of hemoptysis vary depending on the geographic location of the patient; infectious diseases, such as tuberculosis, remain the most prevalent cause in the developing world countries, whereas cystic fibrosis and congenital heart disease are usually the main causes in the western world. Various causes of hemoptysis are listed in Table 1.2

Pathophysiology

The pathophysiology of hemoptysis is dependent on whether an inflammatory process is involved. Chronic inflammatory conditions of the lung (such as tuberculosis, aspergillosis, histoplasmosis, cystic fibrosis, bronchiectasis, chronic bronchitis, etc) recruit systemic blood supply to the inflamed regions through bronchial arteries. When the disease process involves the pleura and/or the chest wall, nonbronchial systemic arteries are often recruited to the inflamed areas. These recruited systemic arteries rupture due to vascular fragility, increased regional blood pressure, and/or formation of pseudoaneurysms or arteriovenous fistulae.3 Often, hemoptysis is preceded by respiratory infection. A few disease processes such as cavitary tuberculosis and lung abscesses may involve the pulmonary arteries and may result in pseudoaneurysms. Hemoptysis occurs from the rupture of such pulmonary artery pseudoaneurysms.

Noninflammatory processes, such as malignancy (primary bronchial carcinoma, metastatic osteosarcoma, and other sarcomas) and congenital heart diseases, may also result in hemoptysis. Although bronchial arteries remain the main supply to the bronchial tumors, nonbronchial systemic arteries are often the source of hemoptysis when the malignancy invades the pleura or the chest wall. Bronchial tumors erode into the vessels and thus lead to bleeding. Congenital heart diseases that result in pulmonary oligemia lead to recruitment of systemic arteries to supply the lungs and may eventually cause hemoptysis. Infection of a sequestrated lung (perfused by an aberrant arterial blood supply from the aorta) is another rare congenital cause of hemoptysis.
Clinical Considerations

The workup of a patient with hemoptysis requires a multidisciplinary team effort involving a pulmonary critical care specialist, a thoracic surgeon, and an interventional radiologist. A complete history and physical examination provide clues to the underlying pathology and the location of bleeding. Often, patients are able to identify the side of bleeding. Chest radiograph provides information on the disease process, location, and involvement of the pleura and may confirm the location of the bleeding. However, when a disease process involves both lungs, a chest radiograph is of limited use in localization of bleeding. Similarly, in the presence of massive hemoptysis, a chest radiograph is of limited use due to aspiration of blood into both lungs. Additionally, the chest radiograph is normal in 20%-30% of patients presenting with hemoptysis.4 Bronchoscopy is useful in identifying the site of bleeding and is often requested before bronchial artery embolization. Bronchoscopy is highly useful if the site of bleeding is inconclusive on clinical examination and on imaging studies, in patients presenting for the first time with hemoptysis, and in the presence of recurrent bleeding following embolization or surgery. It provides detailed evaluation of the upper airway and the central bronchi and allows locoregional therapy through laser coagulation, thrombin/fibrinogen instillation, endobronchial balloon occlusion, and local infusion of vasoactive drugs to control bleeding. However, it has limited use in the presence of massive hemoptysis, as aspirated blood makes it difficult to locate the bleeding site. The overall accuracy of bronchoscopy in evaluating patients with hemoptysis reaches 40%-50%, but it falls to 0%-31% in patients with normal chest radiograph.5

The expanding role of computed tomography (CT) and CT angiography in patients presenting with hemoptysis is becoming well recognized. CT provides excellent details regarding the presence, extent, location, and type of lung pathology. CT scores high in providing the details of vascular anatomy, anomalies, and cause of bleeding (eg, bronchial vs pulmonary). In addition, the origin and course of the bronchial arteries and the involvement of nonbronchial systemic

Table 1 Causes of Hemoptysis

<table>
<thead>
<tr>
<th>Airway diseases</th>
<th>Parenchymal diseases</th>
<th>Cardiovascular diseases</th>
<th>Others</th>
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<tbody>
<tr>
<td>Bronchitis</td>
<td>Tuberculosis</td>
<td>Pulmonary arteriovenous malformation/aneurysms</td>
<td>Trauma</td>
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<td>Bronchiectasis</td>
<td>Histoplasmosis</td>
<td>Pulmonary artery hypertension (primary and secondary)</td>
<td>Foreign body</td>
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<td>Bronchial tumors</td>
<td>Sarcoidosis</td>
<td>Pulmonary embolism</td>
<td>Coagulopathy</td>
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<td></td>
<td>Cystic fibrosis</td>
<td>Congenital heart diseases causing pulmonary oligemia</td>
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<td></td>
<td>Aspergillosis</td>
<td>Aortic aneurysms</td>
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<td></td>
<td>Lung abscess</td>
<td>Bronchial artery aneurysms</td>
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<tr>
<td></td>
<td>Pneumonia</td>
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<tr>
<td></td>
<td>Pneumocloniosis</td>
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<td></td>
<td>Infected sequestration</td>
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<tr>
<td></td>
<td>Other granulomatous and vasculitides</td>
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Figure 1 (A) Right intercostobronchial trunk arises at the level of T5-T6, gives off the first intercostal artery, and continues as the right bronchial artery. The artery is enlarged and there is parenchymal hypervascularity. (B) Following embolization, the artery is completely occluded.
arteries can be visualized on thin-section contrast-enhanced CT. This is useful for planning optimal intraprocedural C-arm orientation and may aid in more rapid selective catheterization of the involved arteries during angiography. CT can provide added information when bronchoscopy and chest radiograph are nondiagnostic. Also, it is noninvasive, poses less potential risk compared with bronchoscopy and provides essential information for therapy planning. The main disadvantages of CT are radiation risk, the need for potentially nephrotoxic contrast material, and potential time delays in obtaining a CT examination.

In addition to the initial patient evaluation through diagnostic studies, attention must be paid to airway management, laboratory analysis (eg, complete and differential blood counts, coagulation profile, blood type, renal function), and hemodynamic status. Patients with mild hemoptysis may be treated with bed rest, postural drainage, and supportive measures for cough and infection. However, in patients with moderate and massive hemoptysis, airway management is critical and early intubation is recommended to prevent drowning of the lungs by the blood-filled airways. Hemodynamic stability can be achieved with transfusion of blood products and systemic vasoconstrictors. Early intervention through bronchial artery embolization or surgery should be sought as early as possible. When CT suggests involvement of the pulmonary arteries, evaluation of the electrocardiogram (for left bundle branch block) and echocardiography (for pulmonary artery hypertension) are necessary before pulmonary angiography is undertaken.

Bronchial artery embolization is now recognized as the first-line management for bleeding control in patients with moderate to massive hemoptysis, while surgery is preferred for definitive treatment of the patient with hemoptysis, given the long-term efficacy of removing the underlying diseased pulmonary tissue. Bronchial artery embolization may therefore be employed as a temporary measure in controlling bleeding in patients who otherwise would benefit from definitive surgery (specifically, in patients with localized diseases, such as bronchial adenoma, aspergilloma, hydatid disease, and trauma) or as a palliative measure in patients who cannot undergo surgery due to the extent of the disease (eg, bilateral disease), nonresectable tumor, poor pulmonary reserve, prior lobectomy, and other comorbid conditions.

Table 2 Bronchial Artery Branching Patterns (described by Cauldwell et al7)

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Incidence (%)</th>
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<tr>
<td>Type 1</td>
<td>Right intercostobronchial trunk and two left bronchial arteries</td>
<td>40</td>
</tr>
<tr>
<td>Type 2</td>
<td>Right intercostobronchial trunk and one left bronchial artery</td>
<td>21</td>
</tr>
<tr>
<td>Type 3</td>
<td>Right intercostobronchial trunk, one right bronchial artery, and 2 left bronchial arteries</td>
<td>20</td>
</tr>
<tr>
<td>Type 4</td>
<td>Right intercostobronchial trunk, one right bronchial artery and 1 left bronchial artery</td>
<td>9</td>
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Table 3 Angiographic Signs that Suggest Source of Bleeding

1. Hypertrophy/enlarged (>3 mm in diameter), tortuous bronchial arteries with parenchymal hypervascularity, and parenchymal staining
2. Bronchial artery aneurysms
3. Bronchial artery to pulmonary vein shunting
4. Bronchial artery to pulmonary artery shunting
5. Active extravasation
Unfortunately, recurrence rates following bronchial artery embolization are high in patients with progressive lung disease.

**Anatomical Considerations**

A thorough knowledge of bronchial artery anatomy is essential when bronchial artery embolization is attempted. Many variations exist in the number, origin, and course of the bronchial arteries.

**Origin of the Bronchial Arteries**

In 70% of individuals the bronchial arteries arise from the descending thoracic aorta between T5 and T6 (Fig. 1). In 20%, the bronchial arteries have an aberrant origin and may arise from the subclavian, brachiocephalic, internal mammary, thyrocervical trunk, inferior phrenic, and pericardio-phrenic arteries or from the abdominal aorta (Fig. 2). In 10%, the bronchial arteries arise from other segments of the descending thoracic aorta, and aortic arch. Aberrant bronchial arteries can be distinguished from the
nonbronchial systemic arteries as they course along the central bronchi.

**Branching Pattern**

The most consistently identified artery (seen in 80%) is the right intercostobronchial trunk (Fig. 1). It usually arises from the anterior-medial surface of the aorta at T5-T6 (classically located at the site where the left main bronchus crosses the descending thoracic aorta). It gives origin to the first intercostal branch and continues as the right bronchial artery. Left bronchial arteries arise separately from the anterior surface of the aorta. A left intercostobronchial trunk is uncommon (Fig. 3), whereas a common bronchial trunk is relatively common, arising from the anterior surface of the aorta, usually below the level of the right intercostobronchial trunk. It divides into the right and left bronchial arteries after a short course. In addition, the bronchial arteries may course vertically upward or downward before coursing into either lung and, as such, the accurate identification of their origin from the thoracic aortogram may be difficult.

**Figure 7** Hemoptysis in a patient with metastatic sarcoma. Right bronchial arteriogram demonstrates multiple hypervascular masses in the right lower lobe.

**Figure 8** Nonbronchial systemic arterial supply to the lung through the left internal mammary artery. The artery was selectively catheterized with a Davis catheter. The branches of the internal mammary artery show hypertrophy with parenchymal hypervascularity.

**Figure 9** Nonbronchial systemic arterial supply to the lung through the long thoracic artery in a patient who presented with massive hemoptysis, secondary to lung metastases from osteosarcoma. Selective long thoracic arteriogram demonstrates a focal hypervascular mass in the left lung.

**Figure 10** Nonbronchial systemic arterial supply through intercostal artery. Arteriography via a right intercostal artery demonstrates hypertrophy of the artery with lung parenchymal hypervascularity.
Cauldwell et al identified 4 classic patterns of bronchial artery branching, as listed in Table 2. Bronchial and intercostal arteries give off dorsal and ventral radicular arteries that supply the dorsal and ventral nerve roots. Anterior medullary arteries also arise from the bronchial and intercostal arteries and communicate with the anterior spinal artery to supply the spinal cord. These have a characteristic “hairpin” appearance on angiography and course vertically in the midline, centered over the spine.

Supply
Bronchial arteries are the main nutrient supply to the lung and course along the bronchi before anastomosing with the pulmonary circulation at the level of the respiratory bronchioles. In addition to supplying the bronchi, the bronchial arteries supply the diaphragmatic and mediastinal portions of the visceral pleura, the middle third of the esophagus, and the subcarinal lymph nodes. The venous drainage is through bronchial veins and pulmonary veins. As described earlier, radicular arteries and medullary arteries supply the nerve roots and spinal cord. The complications related to bronchial artery embolization result from ischemic necrosis (spinal cord infarction, bronchial necrosis, and esophageal necrosis) of organs that are supplied by the bronchial arteries.

Technical Considerations
Bronchial artery embolization was described as early as 1974 and the technique of embolization has not changed signifi-
cantly since then. The arterial access is gained through a femoral (most often) or brachial approach. Some physicians prefer to obtain a thoracic aortogram before selective bronchial artery angiography. Aortography has the advantage of identifying the origin, number, and course of the bronchial arteries and nonbronchial systemic arteries. Selective catheterization of the bronchial arteries may be achieved using various catheter configurations, such as the Cobra, Simmons, Shepherd’s crook, Mikaelsson, or Yashiro catheters. Aberrant bronchial arteries arising from the thoracic aortic arch are extremely difficult to catheterize; a Simmons 2 or a Headhunter catheter may be useful if this situation is encountered and a brachial artery access approach may also be helpful. Once the bronchial artery is selectively catheterized, an angiogram is performed by hand injection of 5-10 mL iodinated contrast material. Digital subtraction angiography is highly useful in identifying the spinal arteries, as is correct anatomical positioning of the patient. The latter allows for rapid identification of the spinal arteries as they course over the center of the spine. A low-osmolar contrast material is recommended for bronchial and intercostal angiography, as use of high-osmolar contrast material is often implicated as one of the causes of spinal ischemia.

It is rare to identify active extravasation of contrast medium during angiography of the bronchial and nonbronchial systemic arteries. Angiographic signs that help identify the source of bleeding are listed in Table 3 (Figs. 1, 2, 4, 5, and 6). Tumors may demonstrate localized hypervascularity and staining of the tumor (Fig. 7). After identifying an abnormal bronchial/nonbronchial systemic artery, a microcatheter is introduced coaxially through the initially used catheter and is advanced into a more stable location. One should confirm that the microcatheter tip is distal to any radicular/spinal arteries before embolization is performed. Embolization is performed slowly under direct fluoroscopy to prevent reflux of the embolic materials as this could result in nontarget embolization of the particles into other vessels, including the aorta and its branches. Embolization is continued until complete occlusion of all the abnormal vessels and near stasis of the contrast medium within the bronchial artery is achieved (Fig. 1).

**Embolic Materials**

The preferred embolic materials include polyvinyl alcohol particles and gelatin sponge. The appropriate size of the embolic materials is determined by several considerations. One must insure that the size of the embolic particles is sufficient to prevent these materials from crossing the bronchial artery to pulmonary arterial/venous anastomoses. Generally, particles of size larger than or equal to 300 μm are used. Smaller particles often will lead to bronchial and esophageal necrosis. In addition, very small particles may more easily result in nontarget embolization into the spinal arteries and may thus cause spinal cord infarction. Liquid embolic agents, such as alcohol and cyanoacrylate, should be avoided as these can cause very distal embolization and lead to complications. In the presence of large bronchial artery to pulmonary shunts, larger particles or gelfoam pledgets may be used. Routine use of embolization coils should be avoided as these occlude the proximal bronchial artery segments and preclude repeat embolization if hemoptysis recurs. However, coils are preferred to occlude proximal (or mediastinal) bronchial artery aneurysms. Another important use of coils is for embolizing abnormal communication pathways between the bronchial and systemic arteries for prevention of nontarget embolization.

![Figure 12](hemoptysis_in_child_with_infected_pulmonary_sequestration.jpg)

**Figure 12** Hemoptysis in a child with infected pulmonary sequestration. (A) Abdominal aortogram demonstrates an enlarged anomalous artery (arrow) arising from the aorta and supplying the right lung. There is parenchymal hypervascularity (arrowheads). (B) Selective contrast injection into the anomalous artery (open arrow) shows parenchymal hypervascularity and venous drainage through pulmonary vein (arrow).
Nonbronchial Systemic Collaterals

As discussed in the previous sections, nonbronchial systemic arteries supply the lung when a disease process involves the pleura and chest wall. These nonbronchial systemic arteries may be the main source of bleeding in patients with hemoptysis or may be a cause of recurrent hemoptysis following bronchial artery embolization. A detailed search for nonbronchial systemic arteries should be performed in all patients presenting with hemoptysis, especially in patients with extensive inflammatory disease, such as tuberculosis. The common culprit, nonbronchial systemic arteries, includes the branches of the subclavian [thyrocervical trunk, internal mammary artery (Fig. 8), costocervical arteries] and axillary arteries [long thoracic artery (Fig. 9)], as well as the intercostal (Fig. 10) and inferior phrenic arteries (Fig. 11). The intercostal arteries may be selectively catheterized using Cobra or reverse curve catheters. The internal mammary artery may be selected with Davis, Vert, or rim catheters, while the thyrocervical trunk and other branches of the subclavian and axillary arteries can usually be selected with a Davis catheter. The inferior phrenic artery may arise either from the aorta immediately above the celiac axis or from the proximal segment of the celiac axis. This can be catheterized with Cobra or reverse curve catheters. As with bronchial artery embolization, superselective cannulation with a microcatheter is recommended before embolization to prevent inadvertent reflux into the vertebral, carotid, and

Figure 13  Hemoptysis in a patient with septic emboli from bacterial endocarditis of right-sided heart valves. Right pulmonary angiogram demonstrates a bilobed, irregularly margined pseudoaneurysm (arrows in A and B). The aneurysm was successfully treated with metallic coils (arrow in C).
subclavian arteries and the aorta. In patients with sequestration, an anomalous systemic blood supply usually arises from the aorta just below the diaphragm (Fig. 12). This vessel can be selectively catheterized using either a Cobra or a Simmons catheter.

Pulmonary Arteries

The pulmonary arteries are the source of hemoptysis in less than 10% of patients presenting with hemoptysis. The common causes are pulmonary artery aneurysms in association with cavitary tuberculosis, septic emboli related pseudoaneurysms (Fig. 13), and pulmonary arteriovenous malformations (isolated or as a part of hereditary hemorrhagic telangiectasia). Pulmonary artery evaluation is indicated when CT shows a pulmonary artery abnormality, when no abnormal vessels are identified during bronchial arteriography, or if bleeding recurs despite adequate embolization of the systemic arteries. Pulmonary artery aneurysms and arteriovenous malformations are embolized with coils or detachable balloons.

Results

Technical success in embolizing the bronchial and other nonbronchial systemic arteries can be achieved in more than 90% of cases. However, immediate clinical success in controlling bleeding is achieved in only 75%-90%. Failure to achieve immediate clinical success may be caused by technical difficulties in catheterizing the bronchial arteries, failure to identify and embolize all involved bronchial and nonbronchial systemic arteries, and the asphyxiation death of some patients. Long-term recurrence rates vary depending on the underlying lung disease; high recurrence rates are noted with aspergillosis (close to 100%), tuberculosis, and bronchial carcinoma. Recurrent bleeding may be a result of recanalization of previously embolized arteries, and/or recruitment of new bronchial and nonbronchial arteries through disease progression. Recurrences can be treated with repeat embolization. It is important to remember that bronchial artery embolization is aimed at controlling bleeding (a palliative procedure), not at treating the underlying disease process. Surgery remains the definitive therapy for prevention of recurrent hemoptysis.

Complications

Complications following bronchial artery embolization are rare. Of all, spinal cord infarction is most dreaded and results in paralysis of both lower extremities. This complication has been reported to occur at a frequency of 1%-6%, although the actual incidence may even be less than that reported. Other rare complications include bronchial and esophageal necrosis. Common complications include chest pain, dysphagia, and fever. Other procedure-related complications include groin hematoma, dissection of the aorta and great vessels, and contrast material induced nephropathy.

Conclusions

Treatment of hemoptysis requires a proactive, team-based approach with early intervention through bronchial artery embolization in patients with moderate to massive hemoptysis. Bronchial artery embolization is well tolerated; it necessitates a thorough evaluation of the bronchial and nonbronchial arteries and subsequent embolization of all abnormal arteries to achieve a high clinical success in controlling bleeding.

References