

Bronchial Artery Embolization*

Experience With 54 Patients

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Objectives: To report our experience with bronchial arteriography and bronchial artery embolization (BAE).

Materials and methods: A review of clinical experience to evaluate the demographics, clinical presentation, radiographic studies, bronchoscopy, and complications of bronchial arteriography and BAE at Mayo Medical Center, Rochester, MN, from 1981 to 2000.

Results: Fifty-four patients underwent bronchial arteriography. There were 34 men and 20 women with a mean age of 53 years. Hemoptysis was the most common indication in 53 patients (98%). Hemoptysis was caused by bronchiectasis (9 patients), pulmonary hypertension (9 patients), malignancy (7 patients), mycetoma (7 patients), and other identified causes (14 patients). The cause could not be identified in eight patients. Bronchoscopy was performed in 49 patients (92%), and the results identified the bleeding lobe in 32 patients, lateralized the side of the bleeding in 5 patients, and were not helpful in 12 patients. Bronchial arteriography revealed hypervascularity (45 patients), bronchial artery hypertrophy (17 patients), hypervascularity with shunting (15 patients), dense soft tissue staining (8 patients), vascular abnormalities (7 patients), and extravasation of contrast (1 patient). BAE was attempted in 54 patients, completed in 51 patients, and was unsuccessful in 3 patients. Overall, 72 embolization sessions were performed with a total of 131 arteries embolized, and the average number of arteries embolized per patient was 2.5. Control of hemoptysis was observed in 46 patients (85%) at 1 month. Rebleeding occurred within 30 days in five patients. Eight patients had recurrent hemoptysis that occurred 30 days after the procedure. The complications of embolization included subintimal dissection of a bronchial artery (two patients), bronchial arterial perforation by a guidewire (one patient), and the reflux of embolic material into the aorta without adverse sequelae (one patient).

Conclusions: BAE is a useful therapy to control both acute and chronic hemoptysis. BAE may help to avoid surgery in patients who are not good surgical candidates. Should hemoptysis recur in these patients, repeat embolization can be performed safely. (CHEST 2002; 121:789-795)

Key words: angiography; arterial embolization; bronchial artery; bronchoscopy; hemoptysis

Abbreviation: BAE = bronchial artery embolization

Hemoptysis, when massive and untreated, has a mortality rate of > 50%.¹ Therefore, significant or life-threatening hemoptysis calls for swift detection of the anatomic source of the hemorrhage so that definitive therapy can be initiated to stop the bleeding. In the management of patients with hemoptysis, chest roentgenography and CT scanning may point to the likely source of hemorrhage by

identifying the potential reason for the hemorrhage. However, bronchoscopy is the more definitive diagnostic test to identify the bleeding site within the tracheobronchial tree. For instance, significant hemoptysis caused by an endobronchial lesion such as bronchogenic carcinoma can be easily identified and treated by bronchoscopic techniques. When bronchoscopic therapy is not feasible or appropriate, other treatments are employed. Since the bronchial circulation is the major source of hemoptysis, therapeutic embolization of bronchial arteries can be performed to stop the bleeding. A prerequisite for embolization therapy is complete angiography of the pulmonary vascular tree. Depending on the clinical scenario, either bronchial and/or pulmonary angiography may be indicated.

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Herein we describe our experience with 54 patients who underwent bronchial arteriography and bronchial artery embolization (BAE) at Mayo Clinic through 2000. Additionally, we review the demographic characteristics, clinical features, results of imaging techniques, complications related to BAE, and follow-up.

MATERIALS AND METHODS

The clinical records of all patients who underwent bronchial arteriography at Mayo Clinic between 1981 and 2000 were accessed through our radiology department. Mayo Clinic in Rochester, MN, is a tertiary referral center, and most of these patients were referred for the evaluation of hemoptysis. The inclusion criteria consisted of all patients undergoing bronchial arteriography and BAE. The clinical records were reviewed, and the following data and images were collected for analysis: age; sex; clinical features; chest roentgenography; chest CT scan; bronchoscopy; bronchial arteriography, BAE, and results; complications related to BAE; and follow-up. In addition, all available arteriograms were re-reviewed to identify the anatomy and study abnormalities, to review the embolization techniques and results, and to identify bronchial arterial origin of the spinal artery, if possible.

RESULTS

We identified 54 consecutive patients who underwent bronchial arteriography. There were 34 men and 20 women, with a mean age of 53 years (range, 4 to 92 years). The two major symptoms were hemoptysis in 53 patients (98%) and dyspnea in 24 patients (44%). One patient with a bronchial artery aneurysm that was found incidentally on a chest roentgenogram was asymptomatic. Thirty-five patients (65%) had acute hemoptysis when they were evaluated, and 18 (33%) had chronic hemoptysis. The etiology of the hemoptysis included bronchiectasis in nine patients (17%), undefined in eight (15%), malignancy in seven (13%), pulmonary hypertension secondary to congenital heart disease in seven (13%), mycetoma in seven (13%), arteriovenous fistula in three (5%), radiation fibrosis in three (5%), tuberculosis in two (3%), primary pulmonary hypertension in two (3%), fibrosing mediastinitis in one (2%), bronchial artery aneurysm in one (2%), bronchial-to-pulmonary artery fistula in one (2%), bronchial artery varices in one (2%), a right middle-lobe bronchus-to-bronchial artery fistula in one (2%), and an aorta-to-bronchial fistula at the site of a previous aneurysm repair in one (2%).

The findings of chest roentgenograms, which were performed in all patients, were abnormal in 47 patients (87%). Chest roentgenograms were suggestive of the etiology of hemoptysis in only nine patients (17%). Seven patients had normal chest

roentgenogram findings (13%). CT scanning was performed in 44 patients (81%), and the findings were abnormal in all patients. In 31 patients (70%), the findings of CT scans were suggestive of the etiology of hemoptysis, and in 9 patients (20%) they were suggestive of focal hemorrhage. Bronchoscopy was performed prior to angiography in 49 patients (91%). Bronchoscopy identified the bleeding lobe in 32 patients (65%), lateralized the side of bleeding but not the specific lobe in 5 patients (10%), and was not helpful in 12 patients (24%).

Bronchial arteriography was performed in all patients. The findings of angiography included hypervascularity in 45 patients (83%), bronchial artery hypertrophy in 17 patients (31%), hypervascularity with shunting in 15 patients (28%), dense soft tissue staining in 8 patients (15%), vascular abnormalities in 7 patients (13%), and extravasation of contrast into the bronchial lumen in 1 patient (2%). Examples of hypervascularity and hypertrophy of the bronchial arteries before and after coil embolization are shown in Figures 1 and 2. All available bronchial arteriograms (which were performed in 44 patients) were re-reviewed, and a spinal artery was identified in 9 patients (20%). Five spinal arteries originated from the left side, and four originated from the right side.

BAE was performed in 51 of 54 patients (94%). In our early experience, this procedure was performed using a selective technique with the catheter position at the origin of the intended vessel. Since the mid 1990s, however, we have exclusively used a "superselective" technique with the use of 3F microcatheters. We were not able to identify a lower risk of rebleeding using the superselective technique. Thirteen patients required more than one embolization session (average, 2.2 sessions; range, 1 to 4 procedures). Overall, there were 72 embolization sessions for the 51 patients with a total of 131 arteries

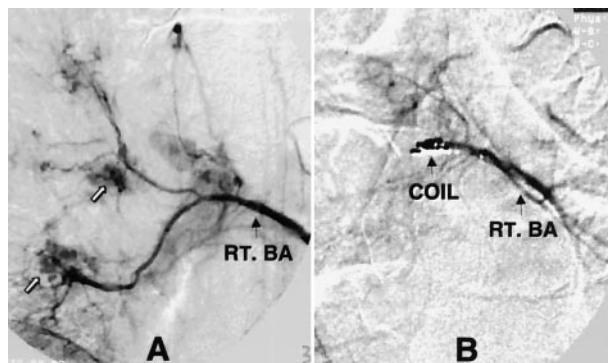


FIGURE 1. *Left, A:* prominent areas of tissue enhancement are seen to be consistent with intense inflammation and hypervascularity (arrows). *Right, B:* after polyvinyl chloride and coil embolization, there is a marked decrease in the hypervascularity.

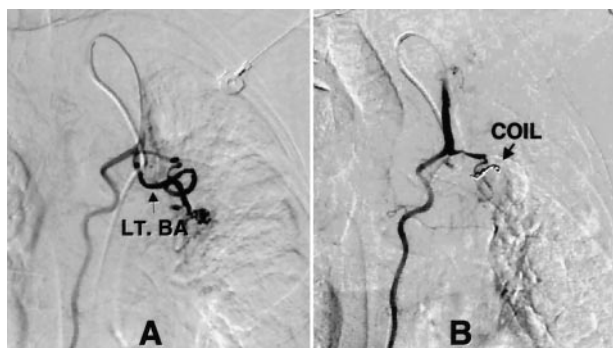


FIGURE 2. *Left, A:* hypertrophied bronchial artery with prominent distal vascularity. *Right, B:* the cessation of blood flow distally is achieved after polyvinyl chloride and coil embolization.

embolized (including bronchial and nonbronchial systemic arteries). The average number of arteries embolized per patient was 2.5. Embolization could not be performed in three patients because of the inability to achieve stable catheter position in two patients and intimal bronchial artery damage caused by the catheter that prevented embolization in the third patient. Numerous other systemic arteries were embolized if they were found to be contributing to the blood supply of the abnormal area. The following arteries were embolized: right bronchial artery (34); left bronchial artery (11); combined right and left bronchial trunk (9); intercostal arteries (45); right internal mammary artery (8); left internal mammary artery (8); inferior phrenic artery (10); lateral thoracic arteries (3); thyrocervical trunk (2); and a left gastric artery (1).

The following agents were used to embolize arteries in our patients: coils, 6 patients; polyvinyl alcohol, 12 patients; coils and polyvinyl alcohol, 25 patients; polyvinyl alcohol and gelatin sponge particles, 6 patients; gelatin sponge particles, 1 patient; and gelatin sponge particles and coils, 1 patient. There was no correlation between rebleeding and the use of any particular agent or the type of embolization performed (proximally with coils alone vs distally with polyvinyl alcohol and/or coils). Of the five patients who developed rebleeding within 30 days, two had been embolized with polyvinyl alcohol alone and three had been embolized with polyvinyl alcohol and coils.

The complications of BAE included subintimal dissection in two patients (4%), arterial perforation by a guidewire in one patient (2%), and reflux of embolic material into the aorta without adverse sequelae in one patient (2%). Pleuritic chest pain postprocedure occurred in two patients (4%), shoulder pain postprocedure in one patient (2%), and transient dysphagia in one patient (2%). One patient developed a groin hematoma at the puncture site.

BAE was successful in controlling hemoptysis immediately in 51 of 54 patients (94%) and at 1 month in 46 patients (85%). Five patients (11%) had recurrent hemoptysis within 1 month of undergoing BAE. Three of these patients died of massive hemoptysis (two patients with bronchogenic carcinoma died 1 and 3 days after undergoing embolization, and one patient with tuberculosis died 10 days after undergoing embolization). One patient with congenital heart disease underwent successful repeat embolization of the right bronchial artery after recanalization had occurred (as well as embolizing the right inferior phrenic and right intercostal arteries that were contributing to the blood supply) and one patient required surgery to remove a mycetoma secondary to massive hemoptysis 1 week after undergoing the BAE. In the three patients (5%) in whom an embolization procedure could not be performed, hemoptysis continued. Of these, one patient died 3 days after the attempted procedure due to massive hemorrhage (malignancy), and the other two patients required surgery (one for the repair of an aorta-to-bronchial fistula at the site of a previous aortic aneurysm repair, and the other for the removal of a mycetoma).

Eight patients had recurrent hemoptysis > 1 month after undergoing BAE. Hemoptysis in two of these patients resolved spontaneously, and in one patient it resolved with antimycobacterial therapy. Two patients developed extensive collateralization requiring embolization of a right bronchial artery and numerous nonbronchial systemic arteries (*ie*, internal mammary artery, internal phrenic artery, and a left gastric artery). These two patients had ongoing pulmonary inflammation, congenital heart disease, and fibrosing mediastinitis. Coils were used for BAE in one patient, and polyvinyl alcohol and coils were used in the other patient. Three other patients developed recanalization of previously embolized arteries as well as collateralization requiring repeat embolization and embolization of nonbronchial systemic arteries.

Seven patients (13%) underwent surgery, two patients in whom BAE could not be performed, two due to recurrent hemoptysis (one from a congenital hemangioma and one from a mycetoma), two for removal of mycetomas, and one due to a celiac plexus blood supply that could not be embolized.

The follow-up revealed that 17 patients (31%) had died, 4 from massive hemorrhage and the remainder as a result of their disease process. There was no follow-up information available on 19 patients (35%). The remaining 18 patients had follow-up periods ranging from 6 months to 6 years without evidence of recurrent hemoptysis.

DISCUSSION

Visualization of the bronchial arteries was first documented in the late 1950s and early 1960s using nonselective aortography.^{2,3} In 1963, Viamonte⁴ performed the first selective bronchial arteriogram. Remy et al⁵ performed the first BAE in 1973 to control hemoptysis. In 1976, Wholey et al⁶ published a series of four cases of successful BAE for the control of hemoptysis. Their embolization materials consisted of gelatin sponge strips (three patients) and topical thrombin injection into the left bronchial artery (one patient). This was followed by a large series by Remy et al⁷ in 1977 of 104 patients who were treated by embolization of both the bronchial and nonbronchial arteries to control hemoptysis. Forty-nine of these patients were treated during active hemoptysis, with immediate control of the hemorrhage seen in 41 patients (84%). Subsequently, BAE was widely used, because nonoperable patients could be treated and other patients could be stabilized prior to surgery.

Bronchial arteriography and embolization were well-tolerated by our patients. An immediate control of bleeding was achieved with embolization in 51 of 54 patients (94%). Our results are similar to those of a study by Mal et al,⁸ who reported that among 56 patients undergoing attempted embolization procedures for hemoptysis, the immediate control of bleeding was achieved in 43 of 56 patients (77%). Cremaschi et al⁹ evaluated 209 patients who had been embolized for hemoptysis and noted that immediate control was achieved after BAE in 205 (98%). Rabkin et al¹⁰ evaluated 306 patients and found that BAE controlled acute bleeding in 278 (91%). Our results and those of the foregoing studies have shown that BAE is an effective procedure with which to stabilize many patients and to definitively treat some patients with hemoptysis. Table 1 compares our results with those of other studies.

Recurrent bleeding despite apparently adequate embolotherapy remains a considerable problem, with bleeding occurring in 9 to 29% of patients after

embolization.⁷⁻¹³ In our series, rebleeding occurred within 30 days in 5 of 51 patients (10%). Others have noted rebleeding within 30 days of embolotherapy in 14 to 29% of patients (Table 1). In the series by Mal et al,⁸ seven patients had recurrent hemoptysis within 1 month of undergoing embolotherapy (16%). In four of these patients, the bleeding developed within 10 days, and a second embolization procedure was performed. In these patients, an additional bronchial or nonbronchial collateral artery was embolized resulting in the successful control of hemoptysis. None of their patients had a recurrence of hemoptysis secondary to recanalization. They further analyzed their outcomes by the type of embolization material that was used. In six patients who developed recurrent hemoptysis within 1 month postprocedure, the embolization materials used included the following: gelatin sponge (two patients); microspheres (two patients); polyvinyl alcohol (one patient); and gelatin sponge plus bucrylate (one patient). There was no further elaboration on this in the publication. Among our patients who experienced rebleeding within 30 days, two were embolized with polyvinyl alcohol alone and the other three were embolized with polyvinyl alcohol and coils. There have not been any studies performed to determine the optimal embolic material that should be used in order to prevent recanalization. Overall, 12 of our 13 patients who developed recurrent hemoptysis were embolized with polyvinyl alcohol either alone or in combination with coils or gelatin sponge particles. The 13th patient with recurrent hemoptysis was embolized with coils alone and underwent successful repeat embolization.

Saluja et al¹⁴ have suggested that coils should not be used for BAE as they cause proximal occlusion and do not allow for repeat embolization if necessary. We agree that coils will prevent repeat embolization of the same artery. However, they do provide a safe, thorough, and proximal occlusion of the artery, which can be difficult to achieve with injectable particles alone. It is still possible to embolize

Table 1—Comparison of Control of Hemoptysis in Patients Undergoing BAE*

Study	Technical Success	30-d Control	Control > 30 d
Remy et al ⁷	41/49 (84)	NA	35/49 (71)
Uflacker et al ¹³	49/75 (65)	NA	39/75 (52)
Rabkin et al ¹⁰	278/306 (91)	239/306 (78)	242/306 (79)
Hayakawa et al ¹¹	50/63 (79)	NA	36/63 (57)
Cremaschi et al ⁹	205/209 (98)	NA	172/209 (82)
Ramakantan et al ¹²	102/140 (73)	72/140 (51)	94/140 (67)
Mal et al ⁸	43/56 (77)	36/56 (64)	39/56 (70)
Present study	51/54 (94)	46/54 (85)	43/54 (80)

*Values given as No. of patients affected/No. of patients in the study (%). NA = data not available.

feeding collaterals if rebleeding develops. Polyvinyl chloride and coils provide permanent occlusion, while gelatin sponge particles are considered to provide temporary occlusion.

Hayakawa et al¹¹ have reported two peak times of bleeding recurrence. The first is from 1 to 2 months after the patient undergoes embolotherapy, which may reflect bleeding from nonbronchial systemic arteries that were not previously embolized. Others have noted the control of hemoptysis at 1 month in 51 to 85% of patients and control at > 1 month in 52 to 82% of patients (Table 1). The second peak for recurrence of hemoptysis is from 1 to 2 years after the patient undergoes embolotherapy. This appears to reflect the recruitment of blood supply and revascularization by the underlying pulmonary inflammation or progression of the underlying disease. Only one of our patients with congenital heart disease developed rebleeding > 1 year after embolization and underwent successful repeat embolization. Recurrent bleeding after embolotherapy may indicate incomplete embolization of the bronchial arteries, the presence of nonbronchial systemic arteries, recanalization of embolized arteries, or collateralization due to continued pulmonary inflammation. In order to eliminate these types of recurrent hemorrhages, it is important to treat the underlying disease condition as well as to perform complete embolization, including the embolization of any systemic arteries that may be contributing to the blood supply.

It is well-documented that bronchial arteries vary significantly in their numbers and sites of origin. More than 70% of bronchial arteries arise from the descending aorta between the levels of the fifth and sixth thoracic vertebrae.¹⁵ Based on a study of 150 human cadavers in 1948, Cauldwell et al¹⁶ defined four types of anatomic variation. The most common type is that of a single right bronchial artery with two left bronchial arteries (41%). Up to 20% of bronchial arteries may have an aberrant origin (from other systemic arteries), and nearly 10% arise from the anterior surface of the aortic arch or the descending aorta. A spinal artery can originate from a bronchial

artery in up to 5% of patients, with right side being more common than the left side. A spinal artery was identified in nine of our patients, with five occurring on the left side and four occurring on the right side.

Significant hemoptysis was the indication for bronchial arteriography in 53 of our patients (98%). Our patients with bronchogenic carcinomas were more likely to have recurrent hemoptysis. This finding is similar to that in the series reported by Hayakawa et al.¹¹ Their 63 patients with neoplasm-induced hemoptysis showed the highest failure rate with the worst long-term results, followed by the inflammation group, the idiopathic group, and the bronchiectatic group. Hirshberg et al¹⁷ studied the etiology, evaluation, and outcome of 208 patients with hemoptysis in a tertiary referral hospital. They found that the most common causes of hemoptysis included bronchiectasis (20%), lung cancer (19%), bronchitis (18%), and pneumonia (16%). In contrast, older studies reported tuberculosis as the most common cause of significant hemoptysis. In the series by Remy et al,⁷ the etiologies of hemoptysis included tuberculosis (34%), bronchiectasis (26%), aspergiloma (18%), pneumoconiosis in coal miners (13%), and bronchogenic carcinoma (3%). Knott-Craig and colleagues¹⁸ retrospectively studied 120 patients with hemoptysis and found that the right lung was the source in 62% and the left lung in 38%, with the right upper lobe being the area that was most commonly affected. Our results were similar in that the right lung was the source of bleeding in 33 patients (61%), the left lung was the source in 17 patients (31%), and both lungs were the source in 4 patients (7%). The right upper lobe was also more commonly involved in our patients. Table 2 compares our findings with those of several other series.

Before bronchial angiography is performed for the evaluation of significant hemoptysis, patients usually undergo tests, including chest roentgenography, chest CT scanning, and bronchoscopy. Chest CT scans have been reported¹⁹ to be superior to bronchoscopy in the evaluation of hemoptysis. Hirshberg et al¹⁷ reported that a chest CT scan, if used alone,

Table 2—Etiology of Hemoptysis in Several Series*

Study	Bronchiectasis	Idiopathic	Malignancy	TB	Mycetoma	PHTN
Remy et al ⁷	26	1	3	34	18	1
Uflacker et al ¹³	NR	NR	1	91	NR	NR
Hayakawa et al ¹¹	17	16	26	NR	1	NR
Cremašchi et al ⁹	47	NR	4	31	3	NR
Ramakantan et al ¹²	0	0	0	100	0	0
Mal et al ⁸	9	22	4	50	2	2
Present study	17	15	13	3	13	17

*Values given as %. TB = pulmonary tuberculosis; PHTN = pulmonary hypertension; NR = data not reported.

was the most sensitive diagnostic test, with a positive yield of 67%, and that if CT scanning was combined with bronchoscopy, then the positive yield increased to 93%. A study by Lampmann and Tjan²⁰ of 50 patients undergoing embolotherapy with long-term follow-up found that bronchoscopy indicated the source of bleeding in 32 of 50 patients (64%). In a retrospective analysis on the management and prognosis of massive hemoptysis, Knott-Craig et al¹⁸ found that rigid bronchoscopy that was performed in 97 of 120 patients with hemoptysis localized the bleeding in only 42 (43%). They also reported that the area of hemorrhage was able to be localized with some degree of confidence in only 63% of patients by a combination of radiologic evaluation, RBC-labeled isotope scanning, and emergency endoscopy. In contrast, our results showed that bronchoscopy was helpful in determining the location of the bleeding. Bronchoscopy identified the bleeding lobe in 65% of patients and lateralized the side of bleeding in 10% of patients.

The complication rate for BAE has diminished gradually over the years. During the early phases of selective bronchial arteriography, several patients developed transverse myelitis as a result of the use of nonionic contrast agents, more neurotoxic materials, and the inadvertent embolization of the spinal arteries. To prevent such neurologic complications, superselective BAE is utilized. This refers to embolization of more terminal branches of the arterial tree, beyond the origin of the spinal arteries. In an effort to compare the safety and efficacy of superselective BAE with those of proximal non-superselective embolization, Tanaka and colleagues²¹ selected 47 patients with hemoptysis. Superselective embolotherapy was performed using a microcatheter inserted into the bronchial artery beyond the spinal or mediastinal branches in 22 patients. In the remaining 25 patients, non-superselective embolization was performed near the origin of the bronchial artery. There were no significant differences between the two groups in the initial or cumulative control of hemoptysis. There were no neurologic complications in the superselective group. One patient in the non-superselective group developed spinal hemiparalysis caused by spinal infarction. The authors concluded that by using superselective embolization distal to the spinal or mediastinal branches, neurologic complications could be avoided and that the embolization may be more effective. This is in contrast to the series by Mal et al,⁸ who observed the following three episodes of spinal cord complications: Brown-Séquard's syndrome, which regressed after 4 months without sequelae; paraparesis with spontaneous regression after 2 weeks; and complete paraplegia without regression. These com-

plications occurred despite good, selective catheterization of the bronchial artery. None of our patients experienced any neurologic sequelae. If a spinal artery arises from a bronchial artery, we will only embolize the bronchial artery if we can achieve a stable distal position well beyond the spinal artery origin.

The complications among our patients were predominantly catheter-related and included subintimal dissection, guidewire perforation, and reflux of embolic agents into the aorta without adverse effects. Transient dysphagia, pleuritic chest pain, shoulder pain, and a groin hematoma also occurred. Ramakantan et al¹² evaluated the results of BAE in 140 patients with tuberculosis and documented postprocedure complications in 12 patients, including transient paraparesis in 2 patients, transient dysphagia in 1 patient, and transient left orbital/forehead pain in 9 patients. The patients who developed left orbital/forehead pain only experienced the pain during the injection of gelatin sponge embolic material into the left bronchial artery and did not experience this pain with the injection of saline solution or contrast medium. The authors hypothesized that this may have occurred as referred pain to the ophthalmic and maxillary divisions of the trigeminal nerve via autonomic afferents reacting to the acute distension of the left bronchial artery during the injection of the gelatin sponge. Chest pain lasting up to 36 h developed in 33 of their patients.

The follow-up of our patients revealed that 17 patients (31%) had died, 4 from massive hemorrhage and the remainder as a result of their disease process. There was no follow-up information available on 19 patients (35%), because they did not return after treatment. The remaining 18 patients (33%) had follow-up periods ranging from 6 months to 6 years without evidence of recurrent hemoptysis.

In summary, BAE is a useful therapy to control both acute and chronic hemoptysis. It is important to embolize nonbronchial systemic arteries at the same setting, if they are angiographically shown to be contributing to the blood supply. It is also important to treat the underlying pulmonary process to decrease vascularity and the development of vascular collaterals. BAE may help to avoid surgery in patients who are not good surgical candidates. Should hemoptysis recur in these patients, repeat embolization can be safely performed. If surgery is indicated, BAE can stabilize the patient prior to surgery. Embolization distal to the spinal artery may significantly decrease the number of complications and may allow a more thorough embolization. Bronchoscopy and CT scanning have important contributing roles in delineating the etiology and/or the source of hemoptysis prior to the patient undergoing bronchial

artery arteriography. Further studies are needed to determine whether any of the various embolic materials currently available is superior in preventing rebleeding.

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