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Factors Associated with the Recurrence of Hemoptysis Following Bronchial Artery Embolization

Bronşiyal Arter Embolizasyonu Sonrasında Nüks Hemoptizi ile İlişkili Faktörler

Eda Cingöz[1], Ali Dablan[2], Mustafa Fatih Arslan[2], Oğuzhan Türksayar[2], Mehmet Cingöz[2], Çağrı Erdim[2], İlhan Nahit Mutlu[2], Tevfik Güzelbey[3], Özgür Kılıçkesmez[4]

[1]University of Health Sciences Turkey, İstanbul Bağcılar Training and Research Hospital, Department of Radiology, İstanbul, Turkey
[2]University of Health Sciences Turkey, Başakşehir Çam and Sakura City Hospital, Department of Radiology, İstanbul, Turkey
[3]Medicana Ataköy Hospital, Clinic of Radiology, İstanbul, Turkey
[4]Memorial Göztepe Hospital, Clinic of Radiology, İstanbul, Turkey

Abstract

Objective: The aim of the current study was to investigate factors associated with recurrent bleeding following bronchial artery embolization (BAE), with particular emphasis on the role of preprocedural computed tomography angiography (CTA).

Method: This retrospective study included 110 patients who underwent BAE for hemoptysis. Patients with and without recurrent bleeding were compared for clinical characteristics, underlying etiology, angiographic features including bronchial and non-bronchial systemic arterial involvement, the number and type of embolized vessels, as well as procedural parameters such as fluoroscopy time, procedure duration, and radiation dose. Factors associated with recurrent bleeding were evaluated using univariate analyses followed by multivariable logistic regression.

Results: Recurrent bleeding occurred in 25 patients (22.7%). The incidence of recurrence was significantly higher in patients without preprocedural CTA compared to those who underwent CTA (36.5% vs. 10.3%, p=0.001). Multivariate analysis demonstrated that the lack of preprocedural CTA was independently associated with recurrent bleeding (odds ratio: 4.985; 95% confidence interval: 1.784-13.926; p=0.002). Mortality was also higher among patients with recurrent however, the difference was not statistically significant (36.0% vs. 21.2% p=0.130).

Öz

Amaç: Bu çalışmanın amacı, bronşiyal arter embolizasyonu (BAE) sonrası rekürren kanama ile ilişkili faktörleri araştırmak ve özellikle işlem öncesi bilgisayarlı tomografi anjiyografinin (BTA) rolüne odaklanmaktır.

Yöntem: Bu retrospektif çalışmaya hemoptizi nedeniyle bronşiyal arter embolizasyonu uygulanan 110 hasta dahil edildi. Rekürren kanama gelişen ve gelişmeyen hastalar; klinik özellikler, altta yatan etiyolojiler, bronşiyal ve bronşiyal olmayan sistemik arter tutulumu, embolize edilen damar sayısı ve tipini içeren anjiyografik bulgular ile floroskopi süresi, işlem süresi ve radyasyon dozu gibi işlem parametreleri açısından karşılaştırıldı. Rekürren kanama ile ilişkili faktörler önce tek değişkenli analizler ile, ardından çok değişkenli lojistik regresyon analizi ile değerlendirildi.

Bulgular: Rekürren kanama 25 hastada (%22,7) gözlendi. İşlem öncesi BTA mevcut olmayan hastalarda rekürrens insidansı, BTA yapılan hastalara kıyasla anlamlı derecede daha yüksekti (%36,5'e karşı %10,3; p=0,001). Çok değişkenli analizde, işlem öncesi BTA'nın olmaması rekürren kanama ile bağımsız olarak ilişkili bulundu (odds oranı: 4,985; %95 güven aralığı: 1,784-13,926; p=0,002). Mortalite sayısal olarak daha yüksekti; ancak fark istatistiksel olarak anlamlı değildi (%36,0'a karşı %21,2; p=0,130).

Address for Correspondence: Eda Cingöz, University of Health Sciences Turkey, İstanbul Bağcılar Training and Research Hospital, Department of Radiology, İstanbul, Turkey
E-mail: edacanipek@gmail.com **ORCID:** orcid.org/0000-0003-0814-4597
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Abstract

Conclusion: The availability of preprocedural CTA prior to embolization is associated with lower rates of recurrent bleeding. It may facilitate a more complete identification of culprit vessels and reduce the likelihood of missed sources and subsequent recurrence.

Keywords: Bronchial artery embolization, computed tomography angiography, hemoptysis, recurrence

Öz

Sonuç: İşlem öncesi BTA'nın mevcut olması, bronşiyal arter embolizasyonu sonrası daha düşük rekürren kanama oranları ile ilişkilidir. BTA, sorumlu damarların daha kapsamlı tanımlanmasını sağlayarak gözden kaçan kanama kaynaklarına bağlı rekürrens olasılığının azaltılmasına katkıda bulunabilir.

Anahtar kelimeler: Bilgisayarlı tomografi anjiyografi, bronşiyal arter embolizasyonu, hemoptizi, rekürrens

Introduction

Hemoptysis is a potentially serious condition that may range from spontaneously resolving bleeding to a fatal compromise of the airways and hemodynamic instability. The underlying etiology varies, depending on geographic and clinical factors; however, lung cancer, active tuberculosis and its sequelae, bronchiectasis, and aspergillosis account for the majority (around 80%) of the cases (1,2).

Severe hemoptysis is considered to be a respiratory emergency and, if left untreated, may be associated with mortality rates as high as 50-100%, most commonly due to asphyxiation rather than exsanguination. Nonetheless, even minor initial episodes, such as blood-streaked sputum or low-volume "index bleeding", may precede life-threatening hemoptysis and therefore warrant early recognition and intervention (3-5). Bronchoscopy plays an important role in maintaining airway patency and localizing the source of bleeding, while surgery remains a definitive option in selected patients; however, both approaches may be limited in an acute setting or in patients at a high risk of mortality (6,7). Bronchial artery embolization (BAE), first introduced into clinical practice in 1973, has evolved into a widely used, minimally invasive, and effective treatment option for controlling hemoptysis. Moreover, advances in microcatheter technology and embolic materials have improved procedural safety and outcomes (8). Despite high technical success and effective initial bleeding control, recurrent bleeding after BAE remains a significant clinical challenge, with reported recurrence rates of up to 57% and an association with increased mortality (9-13). Several factors have been implicated in hemoptysis recurrence after BAE, including incomplete embolization, involvement of non-bronchial systemic arteries (NBSA), larger vessel caliber, as well as recanalization and neovascularization. Given the relatively high recurrence rates, a systematic evaluation of multiple potentially contributing factors is warranted to better understand recurrence patterns and guide clinical management.

The aim of the current study was to investigate factors associated with the recurrence of hemoptysis following BAE, with a particular focus on clinical, angiographic, and procedural variables.

Materials and Methods

Approval for this retrospective study was obtained from the University of Health Sciences Turkey, Başakşehir Çam and Sakura City Hospital Clinical Research Ethics Committee (approval number: 2024-131, date: 24.07.2024), and owing to the retrospective design, the requirement for informed consent was waived.

A total of 111 consecutive patients presenting with hemoptysis at the departments of pulmonology or thoracic surgery and subsequently referred to interventional radiology for BAE were retrospectively evaluated between January 2021 and January 2022. One patient was excluded due to vascular anatomical features that precluded completion of the procedure, leaving a final study cohort of 110 patients who were followed for 12-24 months. Imaging data were retrieved from the institutional picture archiving and communication system and clinical data were retrieved from the electronic medical record system.

The clinical variables evaluated were age, sex, comorbidities, and the presence, frequency, and timing of recurrent hemoptysis following the initial procedure, along with preprocedural computed tomography angiography (CTA), if available. Angiographic and procedural variables included the number and type of embolized bronchial arteries, the presence, location and number of NBSA embolizations, the total number of embolized vessels, fluoroscopy time, procedure duration, and total air kerma. Additionally, angiographic features on digital subtraction angiography, including hypervascularity and tortuosity, and the embolic agents used were also recorded. BAE

procedures were carried out by a team comprising seven interventional radiologists, each with a minimum of five years of experience. The clinical, imaging, and procedural variables collected were compared between patients with and without recurrent hemoptysis.

All procedures were carried out under local anesthesia. Access to the vascular system was obtained through the common femoral artery under ultrasound guidance. Angiography targeting the bronchial arteries and NBSAs thought to be responsible for bleeding was carried out using a 5-F catheter (Cobra or Simmons-1), and additional arteriograms of the bronchial, intercostal, and subclavian territories were obtained to identify abnormal contrast opacification. A 5-F vertebral or Berenstein catheter was used for evaluation of the subclavian artery when indicated. Preprocedural CTA was evaluated, where available, for NBSA feeders and to delineate all potential culprit vascular sources contributing to the hemoptysis. Angiographic runs were carefully reviewed to identify and avoid branches supplying vital tissues, particularly the spinal cord, and heightened attention was applied to vessels originating from the aortic arch, the internal mammary artery, and branches of the subclavian artery to limit unintended embolization. Common bronchial arterial trunks and the left bronchial artery were accessed selectively with standard devices and treated in the absence of retrograde flow, whereas vessels arising from the intercostobronchial trunk, the intercostal circulation, branches of the subclavian system, or the phrenic circulation were managed using a highly selective approach via a coaxial microcatheter system (2.4-2.7 F; Terumo, Tokyo, Japan) in order to decrease off-target embolization. Embolization was performed using polyvinyl alcohol particles (Contour; Boston Scientific, Natick, MA, USA), measuring 500-1180 µm, until adequate flow stasis was achieved. The procedure was concluded once full embolization of all culprit bronchial arteries and NBSAs had been secured (Figures 1, 2). Adjunctive coil and/or n-butyl cyanoacrylate (NBCA)–lipiodol mixture embolization was applied in selected cases based on the preference of the operator.

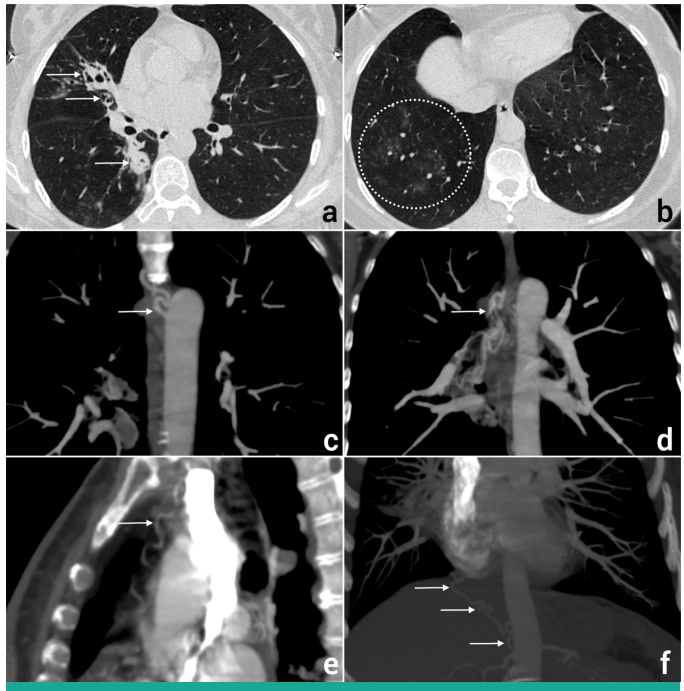

Figure 1. Images of a 61-year-old female patient presenting with hemoptysis, who underwent preprocedural computed tomography (CT) angiography and was subsequently referred to interventional radiology for bronchial artery embolization. a) Axial thorax CT image shows right lung bronchiectasis (white arrows). b) A more inferior axial section demonstrates patchy ground-glass opacities consistent with alveolar hemorrhage (broken white circle) in the patient presenting with hemoptysis. c, d) Coronal maximum intensity projection (MIP) images show hypertrophied and tortuous right intercostobronchial and right bronchial arteries, respectively. e, f) Sagittal and coronal MIP images demonstrate hypertrophied and tortuous right internal mammary and right phrenic artery branches, respectively

Statistical Analysis

Statistical analyses were carried out via IBM SPSS software version 31. The distribution of continuous variables was evaluated with the Shapiro-Wilk test, along with graphical methods. Variables not following a normal distribution were expressed as median (Q1-Q3), while categorical data were presented as counts and percentages. When two groups were compared, the Mann-Whitney U analysis was employed for continuous data that were not normally distributed, while the Pearson chi-square method was utilized for categorical data. Factors associated with recurrent bleeding were first evaluated using univariate analyses. Fisher's exact test was used for 2×2 contingency tables when the assumptions of Pearson's chi-square test were not met, and all statistical tests were two-sided. Parameters showing statistical significance in univariate analyses, together with those deemed clinically meaningful, were then entered into a multivariate model. Etiological variables were not incorporated into the multivariate model because of the small sample size and concerns regarding overfitting. A logistic regression model was employed to determine independent factors associated with recurrent bleeding, with results reported as odds ratios (ORs) and corresponding 95% confidence intervals (CIs). Model calibration was evaluated with the Hosmer-

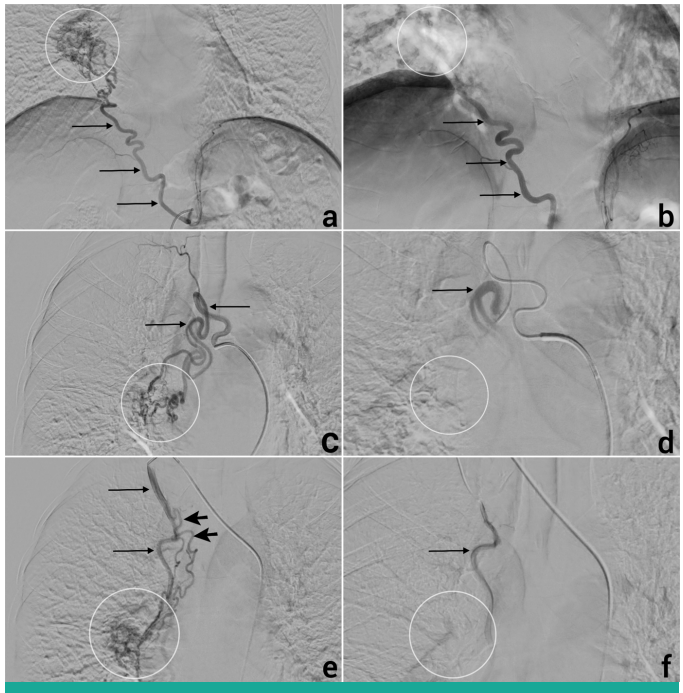

Figure 2. Digital subtraction angiography (DSA) of the patient from Figure 1 who subsequently underwent bronchial artery embolization at the interventional radiology unit. a) Anteroposterior (AP) DSA image demonstrates a focal hypervascularity and vascular blush showing the presumed bleeding site (white circle), that was supplied by the right phrenic artery branches (black arrows). b) Subsequent AP DSA following selective microcatheter embolization shows that the area in a could no longer be visualized (white circle), with flow stasis in the right phrenic artery (black arrows). c) AP DSA after intercostobronchial artery catheterization demonstrates an area of abnormal hypervascularity (white circle) consistent with the suspected bleeding source arising from a right bronchial branch of the intercostobronchial trunk (black arrows). d) AP DSA after selective embolization shows resolution of the area in c (white circle), with proximal stasis in the right bronchial artery (black arrow). e) AP DSA of the right internal mammary artery demonstrates a culprit vascular territory (white circle) supplied by its branches (short arrows) from the main trunk (long arrows). f) Subsequent AP DSA following selective embolization shows disappearance of the area in e (white circle) while preserving patency of the right internal mammary artery (black arrow)

Lemeshow test, while model performance was quantified using the Nagelkerke R^2 coefficient. Statistical significance was defined as a p-value below 0.05.

Results

The study cohort comprised 110 patients. Recurrent bleeding occurred in 25 patients (22.7%) whereas 85 patients (77.3%) had no recurrence. The median age was 57.5 years (interquartile range 44.5-64.2), with a predominance of male patients (n=83, 75.5%) compared to females (27, 24.5%). The most common underlying conditions were pneumonia (20.9%), tuberculosis (16.4%), bronchiectasis (16.4%), and aspergilloma (15.5%), while less frequent comorbidities included chronic obstructive pulmonary disease (5.5%), cardiac pathologies (4.5%), and other diseases. Mortality analysis showed that 27 patients (24.5%) died, whereas 83 patients (75.5%) survived. Preprocedural CTA was available for 58 patients (52.7%), while 52 patients (47.3%) underwent BAE without any preprocedural CTA evaluation.

Age (p=0.889) and sex distribution (p=0.648) did not differ significantly between patients with and without recurrent bleeding. The underlying etiologies differed between the groups, with pneumonia (21.2%) and bronchiectasis (21.2%) being the most frequent in patients without recurrence, while tuberculosis (36.0%) and aspergilloma (24.0%) were predominant among the patients who developed recurrent bleeding. Patients with recurrent bleeding showed a higher mortality rate (36.0%) compared with those without recurrence (21.2%). A significantly higher rate of recurrent bleeding was observed among patients who had not undergone preprocedural CTA (36.5%) compared with those who had (10.3%) (p=0.001; Table 1). A multivariate logistic regression model including age, sex, and preprocedural CTA was statistically significant overall (Omnibus test, p=0.011). The lack of preprocedural CTA was independently associated with recurrent bleeding (OR: 4.985; 95% CI: 1.784-13.926; p=0.002). The lack of preprocedural CTA was independently associated with recurrent bleeding (OR: 4.985; 95% CI: 1.784-13.926; p=0.002), demonstrating a remarkable fivefold increase in the odds of recurrence. Neither age nor sex demonstrated a significant association with recurrent bleeding (p>0.05) (Table 2).

The median time to recurrent bleeding was 2 months (1-5.5), and the median number of recurrent bleeding episodes was 2 (1-3). No statistically significant differences were identified in the number of embolized bronchial arteries between the patients with and without recurrent bleeding (p=0.678). Evaluation of the types of embolized bronchial arteries, including the right bronchial artery, left bronchial artery, common trunk of bronchial arteries, and right intercostobronchial trunk, indicated no significant differences between the two groups (p=0.764, p=0.884, p=0.693, and p=0.677, respectively). Similarly, the use of non-bronchial embolization was comparable between patients with and without recurrence (p=0.891). In addition, neither the number of non-bronchial arteries embolized

Table 1. Comparison of demographic and clinical characteristics of patients with and without recurrent bleeding

Variables	All patients (n=110)	Recurrent bleeding		p
		Absent (n=85)	Present (n=25)	
Age/median (1st-3rd quartiles)	57.5 (44.5-64.2)	58.0 (43.0-63.0)	56.0 (46.5-66.0)	0.889[a]
Sex/n (%)				
Male	83 (75.5)	65 (76.5)	18 (72.0)	0.648[b]
Female	27 (24.5)	20 (23.5)	7 (28.0)	
Comorbidity*/n (%)				
Malignancy	1 (0.9)	1 (1.2)	0	
Tuberculosis	18 (16.4)	9 (10.6)	9 (36.0)	
Pneumonia	23 (20.9)	18 (21.2)	5 (20.0)	
Bronchiectasis	18 (16.4)	18 (21.2)	0	
Aspergilloma	17 (15.5)	11 (12.9)	6 (24.0)	
APVR	1 (0.9)	1 (1.2)	0	
Cardiac disease	5 (4.5)	5 (5.9)	0	
Chronic granulomatous disease	2 (1.8)	2 (2.4)	0	
Pulmonary embolism	1 (0.9)	1 (1.2)	0	
Asthma	3 (2.7)	2 (2.4)	1 (4.0)	
Pulmonary artery aneurysm	1 (0.9)	1 (1.2)	0	
Pneumothorax	2 (1.8)	2 (2.4)	0	
COPD	6 (5.5)	5 (5.9)	1 (4.0)	
Churg-Strauss	3 (2.7)	2 (2.4)	0	
Hypertension	1 (0.9)	1 (1.2)	0	
Behçet disease	1 (0.9)	1 (1.2)	0	
HIV positivity	1 (0.9)	1 (1.2)	0	
Malaria	1 (0.9)	1 (1.2)	0	
Tuberous sclerosis	1 (0.9)	1 (1.2)	0	
Mortality/n (%)				
Deceased	27 (24.5)	18 (21.2)	9 (36.0)	0.130[b]
Alive	83 (75.5)	67 (78.8)	16 (64.0)	
Preprocedural CTA/n (%)				
Absent	52 (47.3)	33 (63.5)	19 (36.5)	0.001[b]
Present	58 (52.7)	52 (89.7)	6 (10.3)	

[a]: Mann-Whitney U test, [b]: Pearson chi-square test, *: Some patients had more than one comorbidity.
APVR: Anomalous pulmonary venous return, HIV: Human immunodeficiency virus, COPD: Chronic obstructive pulmonary disease, CTA: Computed tomography angiography, percentages for preprocedural CTA are expressed as row percentages

Table 2. Multivariable logistic regression analysis of factors associated with recurrent bleeding

Variable	B	OR [Exp(B)]	95% CI	p
Age	0.000	1.000	0.967-1.035	0.992
Sex (male)	0.006	1.006	0.332-3.052	0.991
Preprocedural CTA (absent)	1.606	4.985	1.784-13.926	0.002

Omnibus test: p=0.011; Nagelkerke R^2: 0.145; Hosmer-Lemeshow: p=0.672
Dependent variable: Recurrent bleeding (0= no, 1= yes)
OR: Odds ratio, CI: Confidence interval, CTA: Computed tomography angiography

nor the total number of embolized vessels showed a significant difference between the groups (p=0.474 and p=0.751, respectively) (Table 3).

Fluoroscopy time, procedure duration, and total air kerma did not differ significantly between the patients with and without recurrent bleeding (p=0.225, p=0.283, and p=0.160, respectively). Similarly, no significant differences were observed in the presence of hypervascularity or tortuosity between the two groups of patients (p=1.000 and p=0.468, respectively). Among the 66 patients with available embolic-agent data, particulate embolic agents were used in all cases. The use of adjunctive glue and coil embolization was comparable between the two groups (p=0.318 and p=1.000, respectively) (Table 4).

Evaluation of the procedural parameters according to the availability of preprocedural CTA indicated no significant differences in fluoroscopy time, procedure duration, or total air kerma in the cohort overall (p=0.695, p=0.801, and p=0.923, respectively). Similarly, these parameters remained comparable irrespective of CTA status among the patients without any recurrent bleeding (p=0.839, p=0.815, and p=0.849, respectively) (Table 5).

Discussion

In this study, lack of preprocedural CTA emerged as an independent factor associated with increased odds of recurrent bleeding, and recurrent bleeding tended to be associated with higher mortality.

BAE is a widely applied treatment for hemoptysis with relatively few limitations. Absolute contraindications are mainly related to vessels supplying blood to critical structures such as the heart, brain, or spinal cord; however, in most cases, the risk associated with untreated massive hemoptysis outweighs the procedural risks (3). Despite high initial success rates, recurrent bleeding remains a significant clinical challenge (9,13,14). Early recurrence is often related to incomplete embolization or failure to identify all bleeding sources, whereas late recurrence is typically associated with disease progression, recanalization, or the development of collateral circulation (15). Overlooked culprit vessels have been identified as a leading cause of recurrent hemoptysis on repeat angiography (14).

Efforts to reduce recurrence following BAE have mainly focused on improving the detection and embolization of all

Table 3. Comparison of embolization and angiographic characteristics according to recurrent bleeding

Variables	Recurrent bleeding		p
	Absent (n=85)	Present (n=25)	
Time to recurrent bleeding (months)/median (Q1-Q3)	-	2 (1-5.5)	
Number of recurrent bleeding episodes/median (Q1-Q3)	-	2 (1-3)	
Number of embolized bronchial arteries/median (Q1-Q3)	2 (1-2)	2 (1-2)	0.678[b]
Distribution of embolized arteries*/n (%)			
Right bronchial artery	18 (21.2)	6 (24.0)	0.764[a]
Left bronchial artery	36 (42.4)	11 (44.0)	0.884[a]
Common trunk of bronchial arteries	48 (56.5)	13 (52.0)	0.693 [a]
Right intercostobronchial artery	47 (55.3)	15 (60.0)	0.677[a]
Non-bronchial systemic artery embolization/n (%)	25 (29.4)	7 (28.0)	0.891[a]
Distribution of non-bronchial systemic arteries embolized (n=32)*/n (%)			
Left internal mammary artery	13 (52.0)	4 (57.1)	1.000[c]
Left subclavian artery	1 (4.0)	-	-
Left phrenic artery	2 (8.0)	-	-
Right internal mammary artery	6 (24.0)	2 (28.6)	1.000[c]
Right subclavian artery	2 (8.0)	-	
Right phrenic artery	2 (8.0)	-	
Aberrant/accessory bronchial artery	3 (12.0)	-	
Intercostal artery	7 (28.0)	2 (28.6)	1.000[c]
Subclavian branches	3 (12.0)	1 (14.3)	1.000[c]
Number of non-bronchial systemic arteries embolized (n=32)/median (Q1-Q3)	1 (1-2)	1 (1-2)	0.474[b]
Total number of embolized vessels/median (Q1-Q3)	2 (1.5-3)	2 (2-3)	0.751[b]

[a]: Chi-square test, [b]: Pearson chi-square test; [c]: Fisher's exact test (two-sided), *: Some patients underwent embolization of more than one vessel

Table 4. Comparison of procedural parameters, angiographic findings, and embolic agents used in patients with and without recurrent bleeding

Variables	Recurrent bleeding		p
	Absent (n=85)	Present (n=25)	
Fluoroscopy time (min)/median (Q1-Q3)	27.3 (19.1-35.0)	24.0 (19.0-30.0)	0.225[a]
Procedure duration (min)/median (Q1-Q3)	41.0 (29.0-54.5)	37.0 (26.5-45.0)	0.283[a]
Total air kerma (mGy)/median (Q1-Q3)	515.0 (302.0-961.0)	483.0 (262.0-561.0)	0.160[a]
Hypervascularity/n (%)			
Absent	11 (12.9)	3 (12.0)	1.000[c]
Present	74 (87.1)	22 (88.0)	
Tortuosity/n (%)			
Absent	41 (48.2)	10 (40.0)	0.468[b]
Present	44 (51.8)	15 (60.0)	
Type of embolic agent used *(n=66)/n (%)			
Particle	51 (100.0)	15 (100.0)	-
Glue	3 (5.9)	2 (13.3)	0.318[c]
Coil	10 (19.6)	3 (20.0)	1.000[c]

[a]: Mann-Whitney U test, [b]: Pearson chi-square test; [c]: Fisher's exact test (two-sided) *: Analyses of embolic agents were performed only in patients with available data (n=66). More than one embolic agent was used in some patients

Table 5. Comparison of procedural parameters according to preprocedural CTA availability stratified by recurrence status

Group	CTA	Fluoroscopy time (min)	Procedure time (min)	Total air kerma (mGy)
		Median (1st-3rd quartile)	Median (1st-3rd quartile)	Median (1st-3rd quartile)
Entire cohort (n=110)	Absent	27.2 (21.2-31.6)	39.0 (29.0-49.2)	486.0 (295.2-878.0)
	Present	26.9 (17.0-33.5)	40.0 (23.5-52.7)	520.0 (263.0-714.2)
	p*	0.695	0.801	0.923
Patients without recurrent bleeding (n=85)	Absent	27.9 (21.4-33.9)	41.0 (29.5-54.0)	512.0 (282.0-1021.0)
	Present	27.0 (17.5-35.0)	40.5 (21.2-57.2)	520.0 (298.2-758.7)
	p*	0.839	0.815	0.849
Patients with recurrent bleeding (n=25)	Absent	25.0 (20.0-30.0)	38.0 (27.0-45.0)	483.0 (295.5-611.0)
	Present	19.6 (14.0-24.2)	31.5 (21.0-43.0)	408.5 (128.2-710.5)
	p*	0.092	0.366	0.708

*: Mann-Whitney U test, CTA: Computed tomography angiography

potential bleeding sources, specifically ectopic bronchial arteries and NBSAs, which are frequently implicated in recurrent hemoptysis. Conventional angiography may fail to identify all relevant vascular contributors, particularly small-caliber or tortuous vessels and those arising from atypical or extra-thoracic origins, which may limit comprehensive assessment of the source of bleeding. These limitations have led to increased interest in preprocedural CTA as an adjunctive imaging modality to improve vascular mapping prior to embolization.

Preprocedural CTA has been reported to achieve high diagnostic accuracy, approaching 97.5%, in identifying culprit bronchial arteries and NBSA, thereby facilitating more comprehensive and targeted embolization (16). In addition, it provides superior delineation of the vascular anatomy, particularly in identifying NBSA and anatomic variants that may be overlooked on conventional angiography (17). Furthermore, CTA plays an important role in procedural planning by enabling precise identification of target vessels, which may help streamline the catheterization (18). Consistent with these findings, CTA has also been reported to facilitate the detection of ectopic bronchial arteries and NBSA, particularly those originating from the subclavian and internal mammary arteries, and has been associated with improved hemoptysis-free early survival, supporting its routine use prior to BAE (19).

A prospective study by Le et al. (16), which included 57 patients, reported high diagnostic accuracy (97.5%)

in the identification of culprit arteries with the use of multidetector CTA and was associated with relatively low early recurrence rates (16.7%). In our cohort of 110 patients, recurrent bleeding occurred in 22.7% of cases, with tuberculosis and aspergilloma being the most frequent underlying conditions among the patients with recurrence (36.0% and 24.0%, respectively). Recurrent bleeding in our cohort demonstrated a trend, albeit non-significant, toward increased mortality, consistent with prior reports (13,15). Failure to reach statistical significance may be related to the small sample size. Accurate identification and complete treatment of all potential bleeding sources are therefore essential, which in turn depends on a thorough preprocedural evaluation of the vascular anatomy. In line with prior studies suggesting the clinical relevance of comprehensive vascular mapping and early outcome benefits associated with preprocedural imaging, the present study demonstrates that the lack of preprocedural CTA was independently associated with an increased risk of recurrent bleeding following BAE (16,19).

An important point to consider is that preprocedural CTA was not assigned in a randomized manner in the current study, and the decision to perform CTA may have been influenced by clinical presentation, availability, or clinician preference. Therefore, the potential for selection bias and unmeasured confounding cannot be excluded. It is possible that patients with a more complex disease or challenging vascular anatomy may have been more likely to undergo CTA. Alternatively, patients receiving more comprehensive evaluation and management may have been preferentially selected for CTA. These factors may have contributed, at least in part, to the observed association between the absence of CTA and increased recurrence.

No significant differences were observed in total air kerma, fluoroscopy time, or overall procedural duration between the patients with and without recurrent bleeding. This finding may be partly explained by the additional time required for the embolization of additional vascular territories identified on preprocedural CTA, which could have mitigated potential differences in procedural efficiency between the groups. Moreover, variations in operator experience and technique likely introduced a degree of heterogeneity, further contributing to the overlap in procedural metrics. Taken together, these factors may have negated any measurable differences in exposure to radiation and procedure duration between the patient groups.

Study Limitations

A number of limitations should be taken into account when interpreting the findings. First, the follow-up period was 12-24 months; this duration largely covers the interval during which hemoptysis recurrence after BAE is most frequently observed in the literature. However, within this cohort, the median interval to recurrence was 2 months. Moreover, the relatively limited sample size (n=110) may have constrained the statistical power to identify certain associations. Second, the single-center design may restrict the generalizability of our findings, as patient characteristics, procedural approaches, and operator experience may vary across institutions. In addition, hemoptysis recurrence is a multifactorial process that is influenced by the underlying etiology, vascular anatomy, and procedural factors; therefore, the results warrant cautious interpretation and should not be directly extrapolated to all patient populations. Further prospective, preferably randomized, studies are warranted to better define the factors associated with recurrent hemoptysis following BAE.

Conclusion

Preprocedural CTA may guide the optimal plan for BAE by enabling comprehensive delineation of bronchial and NBSA supply, including accessory and ectopic vessels. Such a detailed anatomic assessment can facilitate a more targeted embolization strategy, reducing the likelihood of missed culprit vessels and subsequent recurrent bleeding. Accordingly, the incorporation of CTA into the preprocedural evaluation may contribute towards improved clinical outcomes in patients undergoing embolization for hemoptysis.

Ethics

Ethics Committee Approval: Approval for this retrospective study was obtained from the University of Health Sciences Turkey, Başakşehir Çam and Sakura City Hospital Clinical Research Ethics Committee (approval number: 2024-131, date: 24.07.2024). The study was conducted in accordance with the Declaration of Helsinki.

Informed Consent: Informed consent was waived due to the retrospective design of the study.

Footnotes

Authorship Contributions

Concept: E.C., A.D., Ö.K., Design: A.D., M.C., Ç.E., İ.N.M., Ö.K., Data Collection or Processing: M.F.A., O.T., İ.N.M.,

T.G., Analysis or Interpretation: A.D., M.F.A., M.C., T.G., Ö.K., Literature Search: E.C., M.F.A., O.T., Ç.E., İ.N.M., Writing: E.C., O.T., M.C., Ç.E., T.G.

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