

Endovascular Management of Tuberculosis-Related Hemoptysis After Thoracic Endovascular Aortic Repair: Anatomical Characterization and Embolization Strategy

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Abstract

Background

This study characterized the anatomical features of aberrant bronchial artery supply in patients with tuberculosis-related hemoptysis after thoracic endovascular aortic repair (TEVAR). It analyzed the technical challenges and strategies of bronchial artery embolization (BAE). The safety and efficacy of adapted embolization strategies were further evaluated. The findings will inform future management of this complex clinical condition.

Methods

This study analyzed the data of patients diagnosed with tuberculosis-related hemoptysis after TEVAR who underwent BAE between January 2021 and September 2024. We characterized the anatomical features of aberrantly supplied bronchial arteries, applied embolization strategies appropriate to each case.

Results

All six patients (mean age 67.3 ± 17.9 years) exhibited aberrant bronchial arterial supply, with 66.7% (4/6) demonstrating multivessel collateral networks originating from the internal thoracic, esophageal, and inferior phrenic arteries. The characteristic vascular anatomy of tuberculosis-related hemoptysis following TEVAR is summarized. Initial transfemoral access was unsuccessful in four cases; however, all were successfully rescued via the transradial approach. Catheterization time through the transradial route was significantly shorter than that via transfemoral access (3–15 vs. 28–45 min). The median dose–area product was $140.85 \text{ Gy}\cdot\text{cm}^2$, and the median total fluoroscopy time was 44.4 min, both positively correlated with anatomical complexity. Technical success and immediate hemostasis were achieved in all patients (100%), with no major complications or recurrence of hemoptysis during follow-up.

Conclusion

Aberrant bronchial arteries in tuberculosis-related hemoptysis after TEVAR demonstrate complex anatomical characteristics. BAE could be performed safely and effectively with preprocedural planning, individualized access selection, and refined superselective techniques. Overall, BAE offers a feasible therapeutic pathway for this challenging condition.

Clinical trial registration

Clinical trial number: not applicable.

Background

Tuberculosis remains one of the world's deadliest infectious diseases, with an estimated 10.8 million new cases and more than 1.2 million deaths globally in 2024.⁽¹⁾ Hemoptysis represents a serious and potentially life-threatening complication of pulmonary tuberculosis, with reported incidence ranging from approximately 8% to 27%, depending on disease history and severity.^(2, 3, 4) If not managed promptly, it can lead to fatal outcomes, such as asphyxiation or hemorrhagic shock.^(5, 6) Approximately 5%–14% of patients with hemoptysis develop massive or life-threatening bleeding, with mortality rates of 9%–38%.⁽⁷⁾ Bronchial artery embolization (BAE) is the established first-line therapeutic intervention for massive or life-threatening hemoptysis.^(8, 9) Its minimally invasive nature, high technical success, and immediate efficacy in controlling bleeding have cemented its role in modern interventional radiology practice.⁽¹⁰⁾

Thoracic endovascular aortic repair (TEVAR) is a well-established first-line, minimally invasive treatment for various thoracic aortic pathologies⁽¹¹⁾. TEVAR repairs aortic lesions by implanting a covered stent in the aorta to isolate the diseased vascular segment.⁽¹²⁾ While this procedure effectively treats the primary aortic pathology, stent-graft implantation can alter the native vascular anatomy and hemodynamics, potentially inducing the development of complex collateral circulation. In patients with concomitant tuberculosis, this vascular remodeling can theoretically reduce the incidence of early-stage hemoptysis by redirecting blood flow away from the bronchial arteries. Nevertheless, once tuberculosis-related hemoptysis occurs in this specific population, embolization becomes considerably more challenging⁽¹³⁾.

However, systematic research on the optimal management of tuberculosis-related hemoptysis after TEVAR is largely lacking. Current guidelines and studies on BAE have mostly investigated cohorts without prior major aortic intervention, leaving significant gaps in procedural planning, embolic material selection, and clinical outcomes in this complex population. The absence of tailored approaches may lead to delayed or suboptimal bleeding control, adversely affecting patient prognosis.

Therefore, this study aimed to elucidate the vascular anatomical changes induced by tuberculosis-related hemoptysis after TEVAR and explored their implications for subsequent embolization strategies. Furthermore, we analyzed the technical challenges encountered during BAE for tuberculosis-related hemoptysis after TEVAR, proposed refined embolization strategies, and evaluated the clinical safety and efficacy of these adapted interventions. Our findings may enhance the management of similar conditions in the future.

Materials and Methods

Ethical statement

This study was approved by the institutional review board of the Hangzhou Red Cross Hospital. All procedures involving human participants complied with the ethical standards of the 1964 Declaration of Helsinki. Given the retrospective design of the study and the use of anonymized data, the requirement for informed consent was waived.

Clinical trial registration

Clinical trial number: not applicable.

Patient selection and management

This study enrolled patients diagnosed with tuberculosis-related hemoptysis after TEVAR who underwent BAE from January 2021 to September 2024. The inclusion criteria were as follows: a diagnosis of tuberculosis-related hemoptysis after TEVAR and age ≥ 18 years. The exclusion criteria were as follows: concurrent malignancies, cases with missing clinical information, and cases lost to follow-up. The multidisciplinary team that managed tuberculosis-related hemoptysis cases included professionals from the emergency, radiology, respiratory, thoracic surgery, and interventional radiology departments.

Data collection

We collected comprehensive data on various demographic characteristics (sex, age, body mass index), clinical presentation (symptoms, hemoptysis volume, hemoptysis etiology), TEVAR background (indication), procedural details (culprit vessel origin, catheterization time, catheter specifications, radiation metrics), treatment parameters (embolic materials), and outcomes (procedural success, complications).

Preprocedural evaluation and vascular access planning

All patients underwent a preprocedural evaluation, which included a comprehensive evaluation of symptoms, causes, and extent of lung involvement. Computed tomography and arteriography (CTA) was performed before BAE in all patients.⁽¹⁴⁾ The target artery was identified using radiography, CTA, or bronchoscopy. Two experienced observers (an imaging physician and a thoracic surgeon), blinded to the clinical information, reviewed all images to identify the target artery. Discrepancies in

identifying the target artery were resolved through consensus. Although the transfemoral artery approach is preferred, it can be challenging; thus, the transradial artery approach is often performed as a supplement. Prior to selecting the radial artery approach, the Barbeau test was performed on the ipsilateral side⁽¹⁵⁾.

Embolization

The femoral or radial artery was catheterized under local anesthesia. A 5-Fr angiographic sheath was placed in the femoral or radial artery. Through the sheath, a 5-Fr Cobra C2 catheter or a vertebral catheter (135° curve) was used for radiography and to identify the target artery. Following the identification and confirmation of the target artery, it was superselectively cannulated with a 2.4-Fr Merit Maestro microcatheter. A repeat angiogram was performed using the microcatheter to confirm the position. Particle embolization was performed as distally as possible to avoid embolization of adjacent spinal arteries. Polyvinyl alcohol particles with diameters of 300–500 µm and 500–700 µm, along with Gelfoam were used to embolize the culprit arteries. The primary endpoint was met when the column of contrast after embolization persisted for at least five heartbeats. Repeat contrast injection was performed after an interval of 2–3 min. Aberrant bronchial artery uptake was angiographically defined as retrograde filling of bronchial arteries through indirect collaterals (e.g., internal thoracic, costocervical, or esophageal arteries) rather than direct aortic origin, typically associated with vessel tortuosity, acute-angle takeoff, or anastomotic connections with adjacent vascular networks.

Follow-up and definitions

All patients were followed up in outpatient clinics for efficacy. Interviews regarding later outcomes were conducted via telephone. Outpatient follow-up was conducted at approximately 1–3 months postoperatively. Patients were followed up by telephone interview every 6 months for 1 year. Telephone interviews included questions about general condition, bleeding volume, and management details. The end of follow-up was defined as the date of hemoptysis recurrence, rehospitalization for complications, or death from any cause. The discharge criteria were the absence of hemoptysis for ≥3 days post-BAE, stable vital signs, and no complications. Hemoptysis recurrence was defined as a hemoptysis volume ≥30 mL/day, requiring repeat BAE or lobectomy, or recurrence resulting in death.

Statistical analysis

SPSS 26.0 statistical software (IBM Corp, Armonk, NY, USA) was used for data analysis. Continuous variables were expressed as mean ± standard deviation, whereas categorical variables were expressed as numbers and percentages. Statistical significance was set at $P < 0.05$.

Results

Patient characteristics

The medical records of seven patients diagnosed with tuberculosis-related hemoptysis after TEVAR who underwent BAE from January 2021 to September 2024 were reviewed. After applying the inclusion and exclusion criteria, six patients (three male, three female) were included in the final analysis. The remaining one patient was lost to follow-up and was thus excluded. The mean age was 67.3 ± 17.9 years (range: 39–84 years). The average body mass index was 19.17 ± 1.86 kg/m². The average mean arterial pressure was 94.22 ± 6.15 mmHg. All patients presented with hemoptysis. The average hemoptysis volume was 113.33 ± 76.59 mL/day. All (100%) had a confirmed diagnosis of active pulmonary tuberculosis. Indications for TEVAR were aortic dissection in five patients and thoracic aortic aneurysm in one patient. The baseline characteristics of the patients are shown in Table 1.

Anatomical Characteristics of aberrant bronchial arteries after TEVAR

All six cases exhibited aberrantly supplied bronchial arteries, with four (66.7%) demonstrating multivessel supply. Specifically, internal thoracic artery participation was observed in Cases 2, 3, and 6; esophageal artery involvement was noted in Case 4; and combined internal thoracic artery and inferior phrenic artery supply was identified in Case 6. In all cases, the bronchial

arteries were supplied via retrograde flow through anastomotic connections within adjacent vascular networks. This distinctive vascular anatomy was most prominently demonstrated in Case 1, as shown in Figure 1.

Treatment strategy and imaging characteristics of BAE

The culprit feeding arteries were identified as follows: costocervical trunk alone (Cases 1 and 5); costocervical trunk with the internal thoracic artery (Cases 2 and 3); costocervical trunk with esophageal arteries (Case 4); and costocervical trunk with the internal thoracic and inferior phrenic arteries (Case 6). The transfemoral approach was initially attempted in all cases but was unsuccessful in Cases 3–6. In these instances, conversion to the transradial approach achieved successful vascular access. Notably, the catheterization time via the transradial route (3–15 min) was significantly shorter than that via the transfemoral approach (28–45 min). A 5-Fr Cobra C2 catheter was used for initial superselection in all procedures. In cases with complex anatomy (Cases 3–6), a 5-Fr vertebral catheter (135° curve) was also used. Final embolization was performed using a 2.4-Fr Merit Maestro microcatheter in all cases. Embolization was consistently achieved using a combination of polyvinyl alcohol particles and Embosphere microspheres. The total fluoroscopy time ranged from 18.5 to 71.5 min, with a mean value of approximately 44.4 min. A positive correlation was observed between procedure duration and anatomical complexity. The total dose–area product ranged from 38.9 to 225.5 Gy·cm², with a median value of 140.85 Gy·cm². The highest radiation exposure was recorded in Case 6, which featured a multivessel supply and the longest procedure time. Technical success was achieved in all cases. Effective hemostasis was achieved in all patients, with no major complications reported. The treatment strategies and imaging characteristics for all BAE cases are shown in Table 2.

Follow-up data

All patients who achieved resolution of hemoptysis were discharged within 3 days of the interventional procedure. The median follow-up duration was 12.5 months (interquartile range, 12–14 months; overall range, 9–15 months), with a mean follow-up of 12.5 ± 2.1 months. At the time of manuscript submission, all patients remained alive, corresponding to a 1-year survival rate of 100%. No recurrence of hemoptysis was observed during follow-up, and no adverse events—including radial artery occlusion, ectopic embolism, or intervention-related mortality—were documented.

Discussion

This study analyzed the anatomical characteristics of aberrant bronchial arteries associated with tuberculosis-related hemoptysis after TEVAR. While the complex anatomy and variable access routes in these patients posed significant technical challenges, BAE was performed safely and effectively through precise preprocedural mapping with CTA and individualized access planning.

BAE is the first-line intervention for hemoptysis, with reported immediate clinical success rates of 70%–99% across studies.⁽¹⁶⁾ While most culprit vessels in typical hemoptysis following TEVAR originate from the bronchial arteries, coverage of native bronchial artery ostia by the stent-graft frequently induces the recruitment of alternative systemic collaterals. In our study, aberrant bronchial perfusion most commonly arose from the bronchintercostal trunk, followed by the internal thoracic artery, esophageal artery, and inferior phrenic artery. Notably, the bronchial supply in these cases often reached the lungs via retrograde flow through intercostal arteries and anastomotic connections with adjacent vascular networks. These aberrant vessels are frequently elongated and tortuous, often exhibiting acute or retrograde takeoff angles. Such anatomical features markedly increase the technical complexity of endovascular access. To our knowledge, most reported cases of hemoptysis after TEVAR have been attributed to complications such as endoleaks or aortobronchopulmonary fistulae.^(17, 18) However, the underlying mechanism of hemoptysis in our series is distinct. In contrast, hemoptysis did not result from a procedural failure or fistula formation; rather, it was a consequence of disease progression despite a technically successful TEVAR. These features can typically be identified on preoperative CTA. Therefore, obtaining comprehensive CTA before intervention is crucial in such patients to facilitate procedural planning and early decision-making on alternative access strategies or the selection of specially shaped catheters.^(19–21)

The choice of vascular access directly influences procedural success and efficiency. In the present study, four cases in which transfemoral access failed were successfully managed by converting to the transradial approach, which significantly shortened catheterization times. Catheterization failure may be attributed to prolonged and tortuous vascular pathways, particularly those with multiple sharp bends or loops, which increase frictional resistance and attenuate the transmission of forward force, thereby impeding stable catheter advancement. Dynamic torsion or fixed kinking along the access route can physically obstruct catheter passage, even when the catheter is preshaped to conform to the vascular anatomy. Although proximal positioning of the guiding catheter was achieved, its stability and backup support were frequently compromised in highly tortuous segments, severely limiting the advancement of microcatheters or guidewires into distal target vessels. The degree and location of vascular curvature are illustrated in Figure 2. Catheterization failure may also result from an unfavorable catheter-to-vessel angle. When the course of the target vessel was opposite to, or formed an acute angle with, the direction of catheter advancement, axial support for catheter entry into the target vessel became inadequate, thereby contributing to cannulation failure. The causes of catheterization difficulties are summarized in Figure 3. The conventional transfemoral approach is often limited by inadequate catheter support and the challenge of achieving stable superselective cannulation when targeting vessels originating from the subclavian axis. In contrast, the transradial approach provides a natural anatomical advantage in such settings, offering a straighter trajectory and better coaxial alignment with subclavian-origin targets.^(22, 23) Consequently, for aberrant bronchial arteries originating proximally from the subclavian system or its branches, the transradial approach should be regarded not merely as a rescue maneuver but as the potentially preferable access strategy.⁽²⁴⁾ To systematically guide access selection, the relevant vascular anatomy relative to the stent-graft should be categorized into three distinct zones: Zone A (proximal zone), the aortic segment above the starting end of the obstructed stent and its branches; Zone B (stent zone), the aortic segment directly obstructed by the stent; and Zone C (distal zone), the aortic segment below the terminal end of the obstructed stent and its branches. If the culprit vessel is located only in Zone A, the ipsilateral radial artery approach should be used; if located only in Zone C, the femoral artery approach should be used. However, if the responsible vessel simultaneously affects Zones A and C, the femoral artery approach should be selected. Nevertheless, if operating through the femoral artery approach is difficult, the radial artery approach should be performed as a supplement. Figure 4 illustrates the proposed vascular zone classification and the corresponding access route selection.

Regarding embolization strategy, the present study used a microcatheter-based, superselective technique with polyvinyl alcohol particles combined with Embosphere microspheres, achieving a 100% technical success rate and immediate hemostasis. Notably, no major complications occurred in any case, particularly spinal cord ischemia, the most serious embolization-related risk.⁽²⁵⁾ This can be attributed to preoperative CTA identification of spinal arterial branches, superselective microcatheter positioning during the procedure, and the use of distal particulate embolization.⁽²⁶⁾ Our experience confirms that even in highly complex collateral vasculature, BAE can be performed safely with meticulous technique and appropriate material selection.

The total fluoroscopy time and dose–area product were positively correlated with anatomical complexity. Case 6, which featured a multivessel supply and a tortuous course, required the longest procedure time and the highest radiation exposure. This case demonstrates the importance of anticipating longer procedure durations and increased radiation exposure in such complex cases, and of considering technical refinements, such as 3D image fusion and low-dose fluoroscopy, to optimize workflow.

This study has several limitations. Because it is a single-center retrospective analysis with a small sample size, selection bias may exist. Furthermore, the follow-up duration was relatively short. Prolonged observation times are needed to observe long-term rebleeding rates and collateral recanalization. Additionally, it should be noted that our institution does not perform TEVAR procedures. As a provincially designated tuberculosis center, our hospital received all six patients in this study specifically for the management of tuberculosis-related hemoptysis following TEVAR procedures that had been performed at other specialized cardiovascular centers within the city. Consequently, we were unable to obtain the total number of TEVAR procedures conducted during the study period at these external centers and therefore could not calculate the incidence of post-TEVAR tuberculosis-related hemoptysis in the general population based on our data. To validate the long-term outcomes of different access routes and embolization strategies, further multicenter, large-scale prospective studies are warranted.

Conclusion

Tuberculosis-related hemoptysis after TEVAR induces the formation of aberrant bronchial arteries that present complex anatomical characteristics. Although BAE is technically challenging in such cases, it could be performed safely and effectively with precise, CTA-based preprocedural evaluation, individualized vascular access planning, and refined superselective embolization techniques. BAE, combined with thorough preprocedural preparation, would provide a feasible approach for managing this clinically challenging condition.

Abbreviations

TEVAR

thoracic endovascular aortic repair

BAE

bronchial artery embolization

CTA

computed tomography and arteriography

TB

tuberculosis

AD

aortic dissection

TAA

thoracic aortic aneurysm

BMI

body mass index

MAP

mean arterial pressure

CT

costocervical trunk

ITA

internal thoracic artery

EA

esophageal artery

IPA

inferior phrenic artery

TFA

transfemoral access

TRA

transradial access

PVA

polyvinyl alcohol

Fr

French

C2

cobra catheter with type C2 curve

VER

vertebral diagnostic catheter with 135° primary curve

DAP

dose-area product

Declarations

Ethics Approval and consent to participate

This study was approved by the Institutional Review Board of Hangzhou Red Cross Hospital. All procedures involving human participants were conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki. Owing to the retrospective design of the study and the use of anonymized data, the requirement for informed consent was waived

Consent for publication

Not applicable.

Availability of data and materials

The data underlying this article are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that there is no conflict of interest.

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Authors' contributions

Dr. Pengfei Zhu contributed to conceptualization; Dr. Pengfei Zhu, Dr. Wanfei Wu, and Dr. Tuniyaz Tursun contributed to formal analysis and writing—review & editing; Dr. Zhidong Kang and Dr. Pengfei Zhu contributed to investigation, data curation, and formal analysis. Dr. Wanfei Wu and Dr. Pengfei Zhu contributed to writing—review & editing. All authors have approved the final draft of the manuscript.

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Tables

Table 1

Baseline characteristics of patients with tuberculosis-related hemoptysis after thoracic endovascular aortic repair

Variables	Value
Patients (n)	6
Female, n [%]	3 [50%]
Age (years), mean $\pm$ SD	67.3 $\pm$ 17.9
BMI, (kg/m ²), mean $\pm$ SD	19.17 $\pm$ 1.86
MAP, (mmHg), mean $\pm$ SD	94.22 $\pm$ 6.15
Symptom	Hemoptysis (6/6, 100%)
Hemoptysis volume, (mL/d), mean $\pm$ SD	113.33 $\pm$ 76.59
Causes of hemoptysis	TB (6, 100%)
Indications for TEVAR	AD (5, 83.34%) TAA (1, 16.66%)
TB: tuberculosis; AD: aortic dissection; TAA: thoracic aortic aneurysm; BMI: body mass index; MAP: mean arterial pressure	

Table 2
Treatment strategy and imaging characteristics of bronchial artery embolization

Variables	Origin of the culprit vessel	Time to culprit vessel catheterization		Catheter types and sizes	Total DAP (Gy·cm ²)	Total fluoroscopy time (min)	Treatment	Follow-up duration	Outcome
		TFA	TRA						
Case 1	CT	10 min	/	5Fr C2 + Merit Maestro 2.4 Fr	38.9	18.5 min	PVA + embosphere microspheres	9 months	Success
Case 2	CT + ITA	20 min	/	5Fr C2 + Merit Maestro 2.4 Fr	88.2	26.1 min	PVA + embosphere microspheres	12 months	Success
Case 3	CT + ITA	30 min/Failure	5 min	5Fr C2 + 5Fr VER 135° + Merit Maestro 2.4 Fr	145.2	45.7 min	PVA + embosphere microspheres	15 months	Success
Case 4	CT + EA	35 min/Failure	7 min	5Fr C2 + 5Fr VER 135° + Merit Maestro 2.4 Fr	175.6	55.6 min	PVA + embosphere microspheres	13 months	Success
Case 5	CT	28 min/Failure	3 min	5Fr C2 + 5Fr VER 135° + Merit Maestro 2.4 Fr	136.5	43.1 min	PVA + embosphere microspheres	12 months	Success
Case 6	CT + ITA + IPA	45 min/Failure	15 min	5Fr C2 + 5Fr VER 135° + Merit Maestro 2.4 Fr	225.5	71.5 min	PVA + embosphere microspheres	14 months	Success

CT: costocervical trunk; ITA: internal thoracic artery; EA: esophageal artery; IPA: inferior phrenic artery; TFA: transfemoral access; TRA: transradial access; PVA: polyvinyl alcohol; Fr: french; C2: cobra catheter with type C2 curve; VER: vertebral diagnostic catheter with 135° primary curve; DAP: dose-area product

Figures

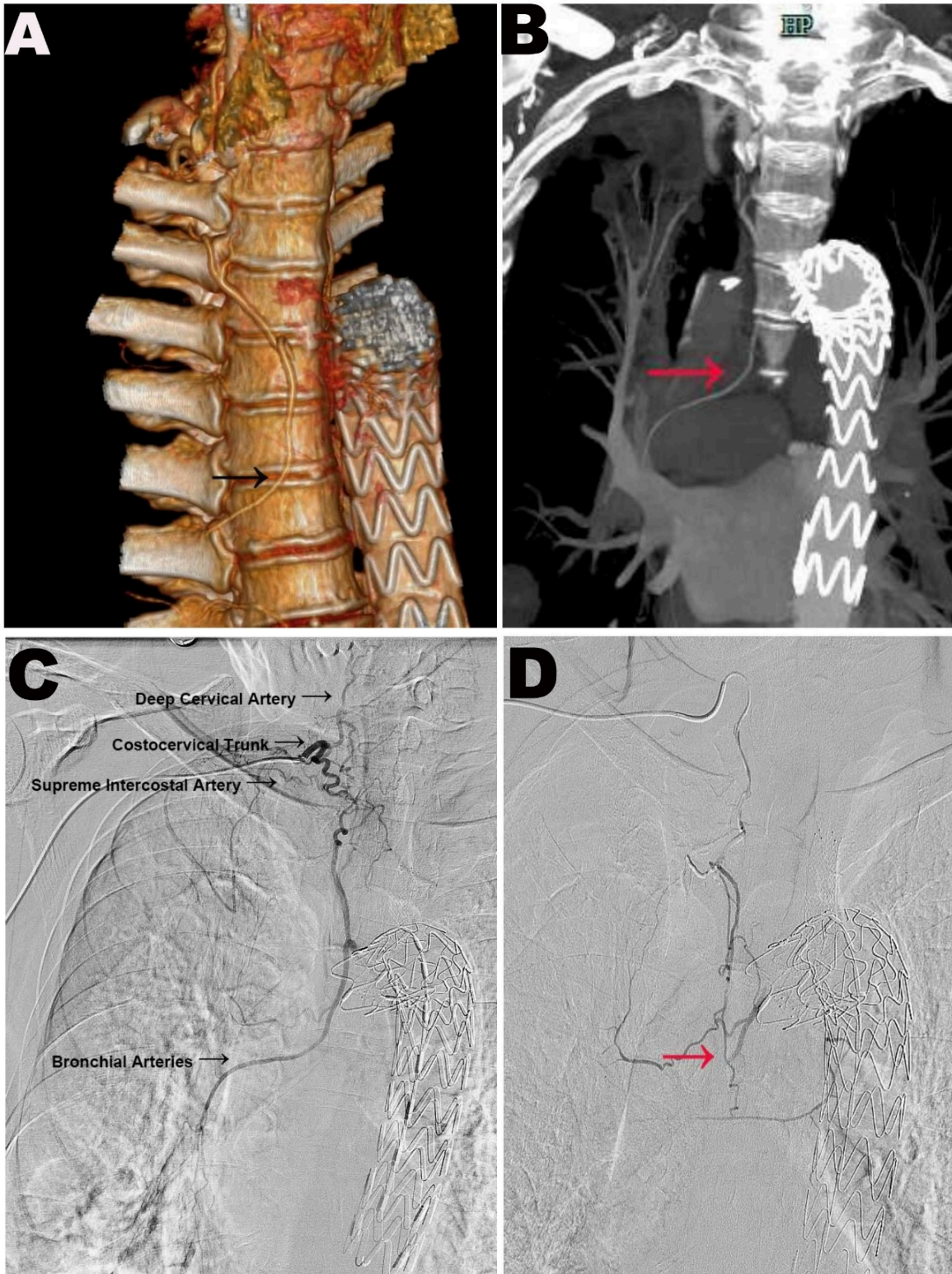


Figure 1

The typical vascular anatomy of tuberculosis-related hemoptysis after TEVAR.

A) Three-dimensional computed tomography angiography showing an aberrant bronchial artery with collateral supply from the costocervical trunk (arrow). B) Three-dimensional computed tomography angiography showing an aberrant bronchial artery with collateral supply from the costocervical trunk (arrow). C) Superselective angiography of the costocervical trunk delineating the detailed course and anatomical correlations of this aberrant bronchial artery with the deep cervical and supreme

intercostal arteries (arrow). D) Post-embolization control angiography confirming the complete occlusion of the target aberrant bronchial artery (arrow).

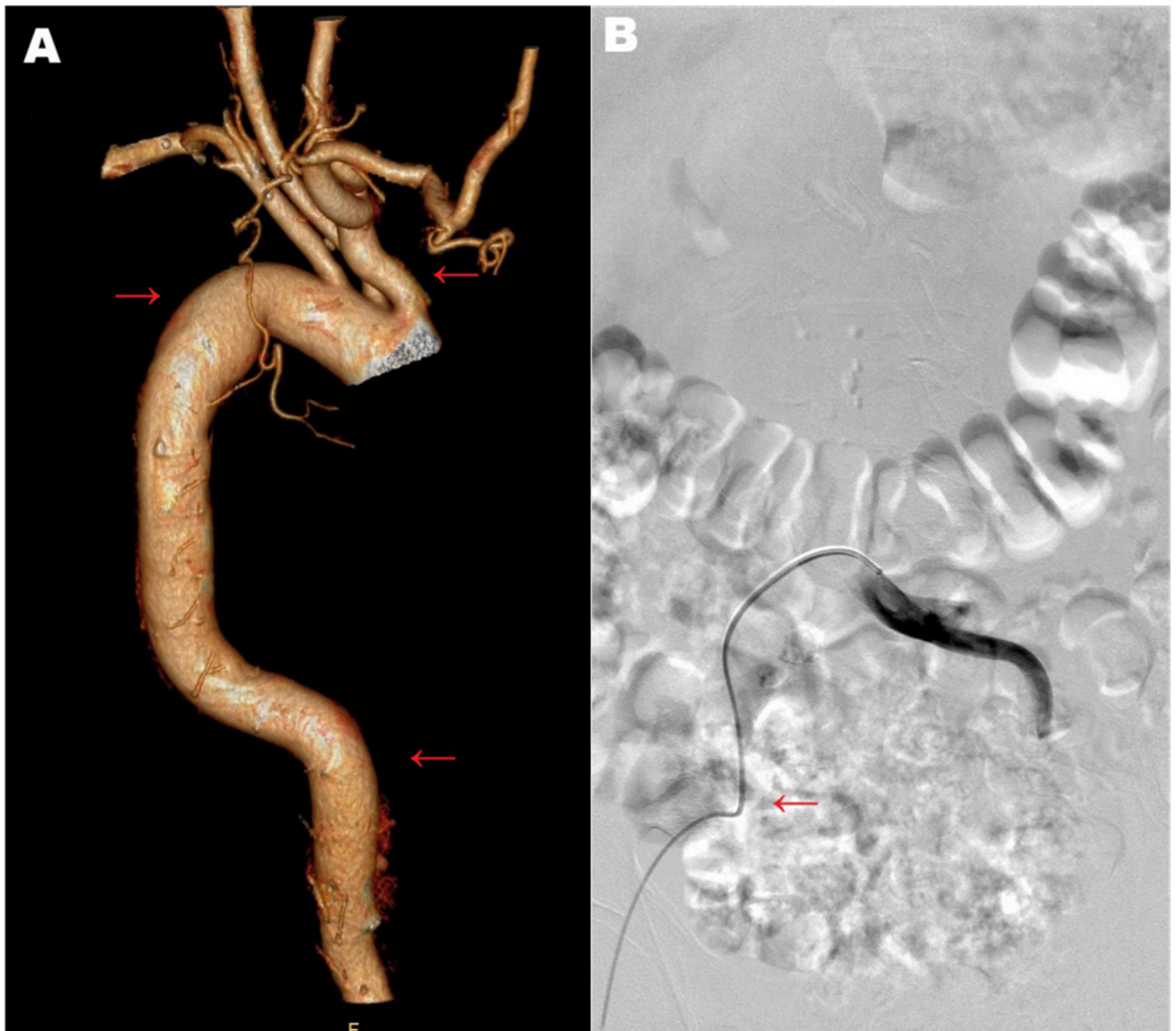


Figure 2

Common anatomical sites of vascular tortuosity and angulation encountered during the embolization pathway.

A) Three-dimensional computed tomography angiography delineating anatomical sites susceptible to vascular tortuosity and angulation along embolization pathways (arrow). B) Angiography via the femoral artery approach revealing a tortuous, angulated iliac artery (arrow).

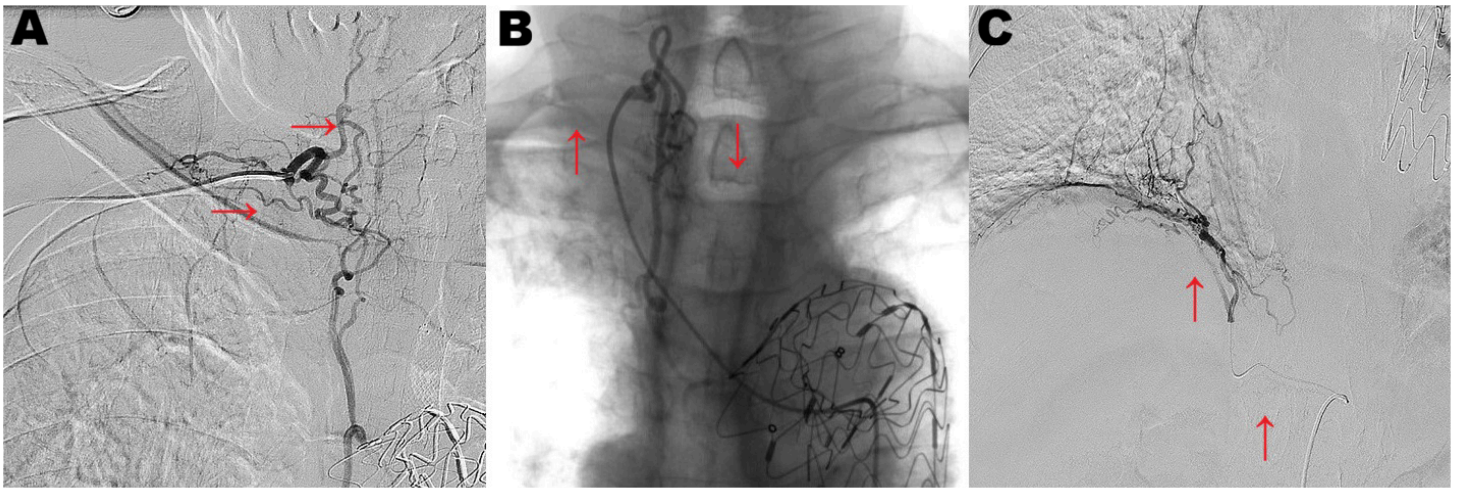


Figure 3

Causes of catheterization difficulties.

A) Coaxial alignment between the catheter force direction and the vessel, which facilitates catheterization (arrow). B) In contrast, this panel shows opposing directions between the catheter force and the vessel, creating difficulty in cannulation (arrow). C) Coaxial alignment between the catheter force direction and the vessel axis facilitates successful catheterization (arrow).

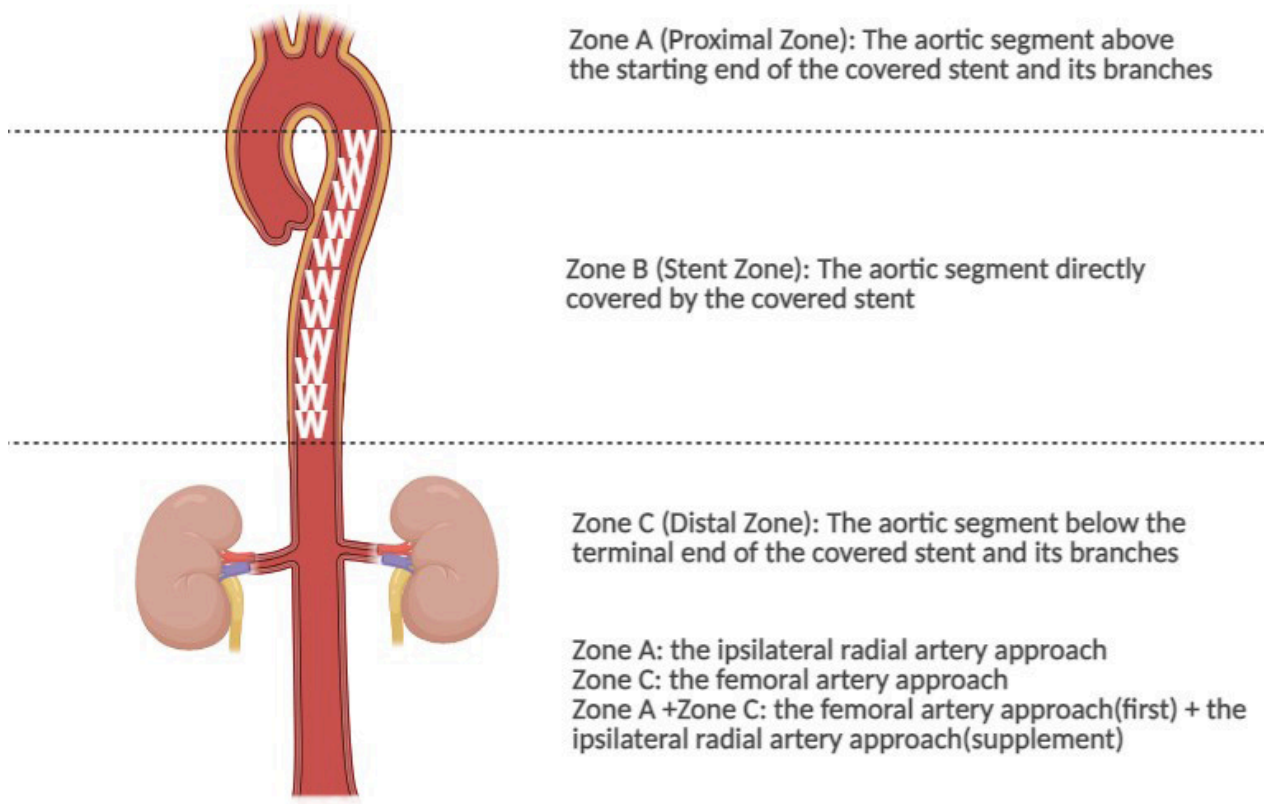


Figure 4

Proposed vascular zone classification and the corresponding access route selection.