Chapter 11
Thoracic Interventional Radiology

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Background

The interventional radiologist has a significant role in the management of vascular and nonvascular pathologies in the thorax and serves an important role as part of the treatment team by providing expertise in image-guided percutaneous interventions. Interventional radiology procedures of the thorax are a well-established field, with percutaneous transthoracic lung biopsy (PTLB) first described by Dahlgren and Nordenstrom in 1966 [1]. In the diagnosis of thoracic pathologies, percutaneous thoracic biopsy (PTB) of lung, pleural, and mediastinal tissue and cells is comparable in effectiveness to surgical biopsy with reduced morbidity and complications [2].

Percutaneous Thoracic Biopsy

PTB provides a minimally invasive method by which lung, mediastinal, or pleural tissue can be collected in order to diagnose thoracic pathologies. The goal of the procedure is to obtain enough tissue or cells required to meet diagnostic needs for pathologic assessment. PTB is now primarily done under computed tomography (CT) but can also be done under fluoroscopy and ultrasound guidance for pleural-based lesions [2]. Imaging modality of choice for procedural guidance depends on lesion location and operator preference [2]. Biopsy can be done using fine-needle aspiration (FNA) for cytology or core needle biopsy (CNB) for pathologic tissue analysis [3].

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Percutaneous Transthoracic Lung Biopsy

Indications

Indications for PTLB [2–5] are based on the SIR percutaneous needle biopsy guidelines developed by Gupta et al. in 2010 and the British Thoracic Society (BTS) guidelines developed by Manhire et al. in 2003 and may include [4, 6]:

- Targeted focal lung lesions
- Lesion or nodule inaccessible via bronchoscopy
- Lesions with inconclusive/nondiagnostic bronchoscopic biopsy results
- Multiple nodules in patient with no known malignancy, with prolonged remission or with more than one primary malignancy diagnosis
- Focal infiltrates persisting over time with no diagnosis based on other investigations
- Mass/lesion present in hilum
- Collection of tissue for microbiologic analysis in cases of suspected or known infection
- Diagnosis and characterization diffuse parenchymal diseases

Contraindications

All contraindications for this procedure are relative, and the risks of the procedure should be weighed against the benefit of performing it prior to making a decision to biopsy [2]:

- Increased risk of bleeding or current use of anticoagulation therapy: platelet count <50,000/ml and aPTT ratio or PT ratio >1.5
- Emphysema
- Presence of bullae
- Impaired lung function
- Prior pneumonectomy
- Pulmonary hypertension
- Lack of patient cooperation
- Predicted forced expiratory volume in 1 s (FEV1) of less than 35 % [4]

Pre-procedural Assessment and Imaging

Pre-procedural imaging (primarily chest radiographs, CT scans, or PET/CT) is assessed to locate the lesion to be biopsied, determine appropriateness of biopsy, and plan the access approach to the lesion in order to perform the procedure [4]. Coagulation indices including prothrombin time (PT), activated partial thromboplastin time (aPTT), and platelet count are determined. Oral anticoagulants should be managed (stopped or left unchanged) based on anticoagulation use guidelines outlined in Chap. 5 [2, 4].

Imaging Guidance

PTB can be completed under CT, ultrasound, or fluoroscopic guidance. Ultrasound is the least expensive, safest, and fastest method for image guidance but can only be used when lesions are located peripherally and contact the pleura (less than 30 % of all thoracic lesions) [2]. CT guidance provides axial imaging slices and can be used for lesions unsuitable for ultrasound guidance (Fig. 11.1) [2]. In some cases, such as highly mobile lesions, fluoroscopy or CT fluoroscopy may be useful for real-time visualization of needle position [3].

Procedure

- PTB can be performed under local anesthetic where possible without sedation [4].
- The patient should be positioned in order to minimize the length of aerated lung traversed.
- A radiopaque grid is used to map the optimal access point.
- After administration of local anesthetic, with or without sedation, a small incision is made using a scalpel blade.
- At this point, a biopsy coaxial needle, with needle size selected by the interventional radiologist based on the lesion size and depth, is introduced into the target tissue.
- A biopsy gun loaded with a coaxial biopsy needle (usually 20 gauge) is then carefully introduced and activated.
- Two or three tissue or cell samples are collected and sent for diagnostic analysis and sample characterization.

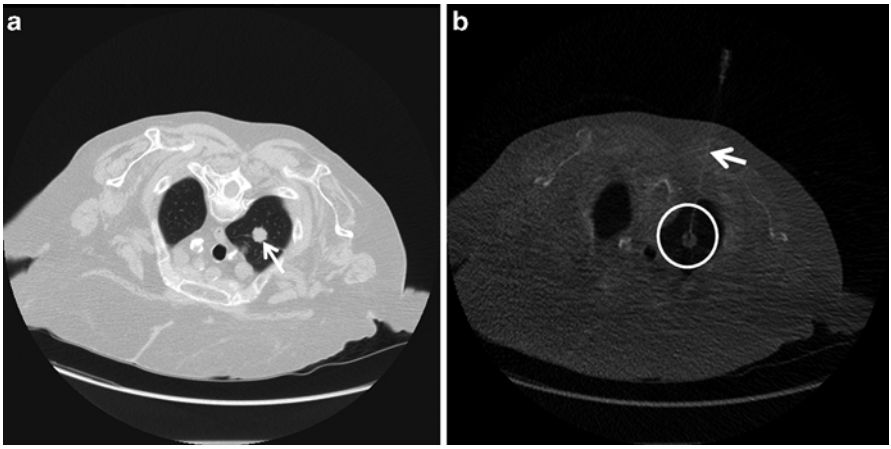

Fig. 11.1 Axial CT of thorax with (**a**) focal lung lesion (*solid arrow*) and (**b**) biopsy needle (*solid line*) placed under CT guidance transthoracically into lesion (*circle*)

Complications

Reported complications of PTB include pneumothorax, tumor implantation, air embolism, subcutaneous emphysema, mediastinal emphysema, empyema, bronchopleural fistula, and bleeding complications including hemoptysis, hemothorax, arteriobronchial fistula, and pulmonary hemorrhage [6].

Of these complications, the most common are pneumothorax and pulmonary hemorrhage. Estimated mortality from this procedure has been reported between 0.07 and 0.15 % [7, 8]. Pneumothorax occurs in 12–45 % of cases, and of these cases, 2–15 % require chest tube insertion for pneumothorax management [6]. Variability in pneumothorax rates is due to varying patient populations, differences in pneumothorax definition and diagnosis, as well as the type of imaging used in the intra- and post-procedure assessment to characterize pneumothorax. Risk factors for pneumothorax include large biopsy needles used, number of pleural punctures, size and depth of lesion, preexisting lung disease, lack of patient cooperation, and operator inexperience.

Pulmonary hemorrhage has been reported without hemoptysis in 5–17 % of patients and with hemoptysis in 1.25–5 % of patients [7, 8]. Risk factors for hemorrhage include increasing lesion depth, long biopsy path, small lesion size, and emphysema.

Post-procedure Imaging

Imaging in the post-procedure setting is important for the assessment of immediate and delayed patient complications following lung biopsy, particularly pneumothorax [2]. Upright chest radiographs and chest CT can be used in the post-procedure setting to assess for complications immediately after the procedure is concluded and should be repeated prior to discharge or if patients develop clinical signs of complications.

Outcomes

Reported success rate for thoracic or pulmonary needle biopsy ranges from 77 to 96 % [3, 6]. Comparison of CNB and FNA diagnostic accuracy rates across different types of biopsy findings showed comparable diagnostic accuracy for FNA in malignant tumors (85.1 % versus 86.7 %) and malignant epithelial neoplasms (86.4 % vs. 85.2 %) with higher diagnostic accuracy in CNB for malignant nonepithelial neoplasms (96 % vs. 77 %) as well as benign-specific lesions (92 % vs. 40 %) [3].

Mediastinal Biopsy

Indications and Contraindications

Percutaneous image-guided biopsy of mediastinal lesions is indicated for lesions which are inaccessible to mediastinoscopy or transbronchial biopsy. There are several contraindications to this procedure which are similar to those for percutaneous lung biopsy including [2, 5, 9]:

- Increased risk of bleeding or anticoagulation therapy: platelet count <50,000/ml and aPTT ratio or PT ratio >1.5
- Lack of patient cooperation

The procedure may not be contraindicated in patients with poor lung function due to lower risk of pulmonary complications [2, 5, 9].

Image Guidance and Procedure

Percutaneous image-guided mediastinal biopsy is done under CT guidance. Ultrasound guidance is primarily for anterior mediastinal lesions and provides real-time feedback on needle positioning and access. Multiple approaches can be used depending on patient factors and target lesion location including extrapleural, transpulmonary, or direct mediastinal (parasternal, paravertebral, transsternal, suprasternal, subxiphoid) approaches. Direct mediastinal approaches utilize the extrapleural space medial to the lungs in order to avoid lung and pleural tissue. The most commonly used technique is a coaxial approach utilizing a guide needle positioned near the target lesion and advancement of the biopsy needle through the guide needle to complete tissue collection.

Complications

Complications include [5]:

- Vascular injury
- Esophageal perforation
- Tracheobronchial injury
- Mediastinitis
- Chylothorax
- Pericardial rupture
- Pneumothorax
- Phrenic nerve injury
- Arrhythmias

Post-procedure Imaging

Post-procedure imaging is targeted toward identifying developing complications prior to clinical symptom development. Chest radiograph or, occasionally, CT scan is performed immediately post-procedure and prior to discharge [2].

Percutaneous Drainage of Thoracic Fluid Collections

Image-guided percutaneous aspiration with or without drainage of fluid or air within the thorax is considered a first-line therapy. Image guidance provides improved safety and efficacy of the procedure over blind techniques. Fluid collections can occur in the pleural space, pericardium, lung, or mediastinum. Pleural fluid collections include pleural effusions, empyema, hemothorax, and chylothorax (chyle accumulating in the pleural cavity). Pulmonary fluid collections include abscesses, pneumatocele, and bullae. Mediastinal fluid collections include abscesses, pericardial effusion, and tension pneumomediastinum [2].

Indications

Indications include [2, 10]:

- **Pleural effusion**: small pleural effusion can be managed conservatively without aspiration or drainage, while large, symptomatic, or malignant pleural effusions require aspiration or drainage (Fig. 11.2).
- **Empyema**: requires drainage in addition to antibiotic therapy for management. Drainage needs to occur early in order to prevent progression of empyema to organized phase. If percutaneous drainage fails, surgical drainage and decortication are the next steps in management.
- **Hemothorax**: usually occurs in a posttraumatic setting and needs to be drained using large-bore chest tubes. Fibrinolytic agent injection may be required in addition to drainage. Depending on the source of the bleeding, arterial embolization may be required prior to drainage.
- **Chylothorax**: low-output chylothorax can be managed conservatively using thoracentesis or chest tube drainage until the thoracic duct leak closes, whereas high-output chylothorax will need surgical intervention for thoracic duct leak closure [11].
- **Abscesses**: may require percutaneous drainage if medical treatment, postural drainage, and bronchoscopic drainage are ineffective (Fig. 11.3).
- **Pneumatocele and bullae**: drainage is indicated in infected or tension pneumatocele.

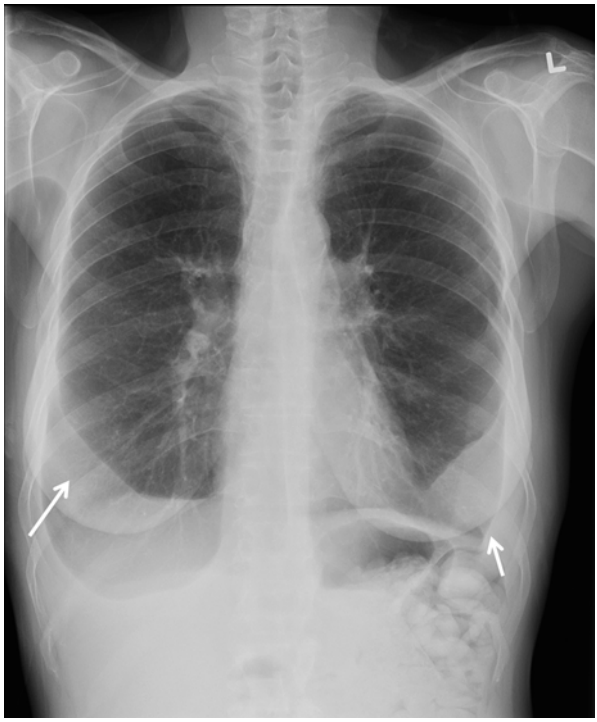

Fig. 11.2 Bilateral pleural effusions, right larger than left (*solid arrows*) on chest radiograph

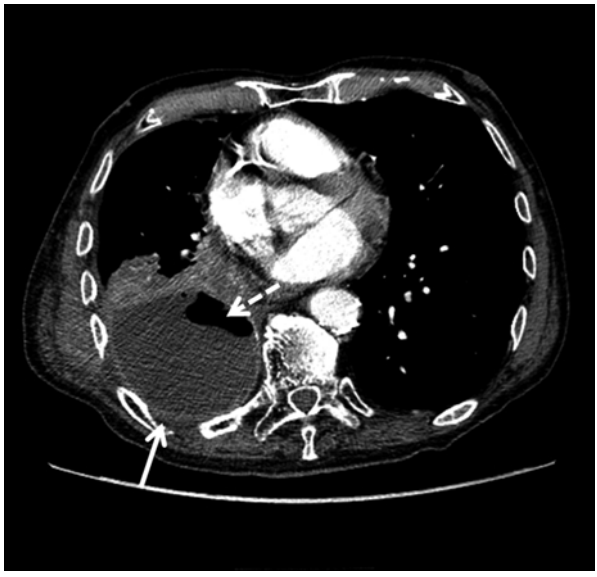

Fig. 11.3 Right lower pleural collection (*solid arrow*) with air-fluid level inside (*dashed arrow*) on axial CT suggestive of abscess

- **Pericardial effusion**: diagnostic pericardiocentesis is indicated if origin is not known and therapeutic pericardiocentesis may be considered for symptomatic or large pericardial effusion [12].
- **Tension pneumomediastinum**: this is an emergency that requires intervention and is primarily managed through mediastinostomy or percutaneous catheter venting under CT guidance.

Contraindications

Contraindications include [2, 10]:

- Increased risk of bleeding or anticoagulation therapy: platelet count <50,000/ml and aPTT ratio or PT ratio >1.5
- Uncooperative patients
- Intractable coughing or breathing
- Patients unable to tolerate procedure-induced pneumothorax
- Skin surface infection

Procedure

Percutaneous image-guided fluid drainage and aspiration is primarily done under ultrasound or CT guidance. Ultrasound guidance is preferred for fluid collections located peripherally in the thorax due to real-time guidance, decreased cost, decreased radiation, and ease of use. Aspiration and drainage are primarily done under local anesthetic with sedation in some situations [10].

Complications

Complications include [2, 10]:

- Procedure failure
- Pneumothorax—increased risk when using large-bore needles or aspirating/draining larger quantities of fluid
- Hemorrhage—avoid subcostal approach in order to reduce risk of laceration of intercostal vessels
- Re-expansion pulmonary edema—increased risk of occurrence when lung tissue has been collapsed for longer duration and large amount of fluid is drained.
- Visceral injury
- Empyema or infection spread following lung abscess drainage

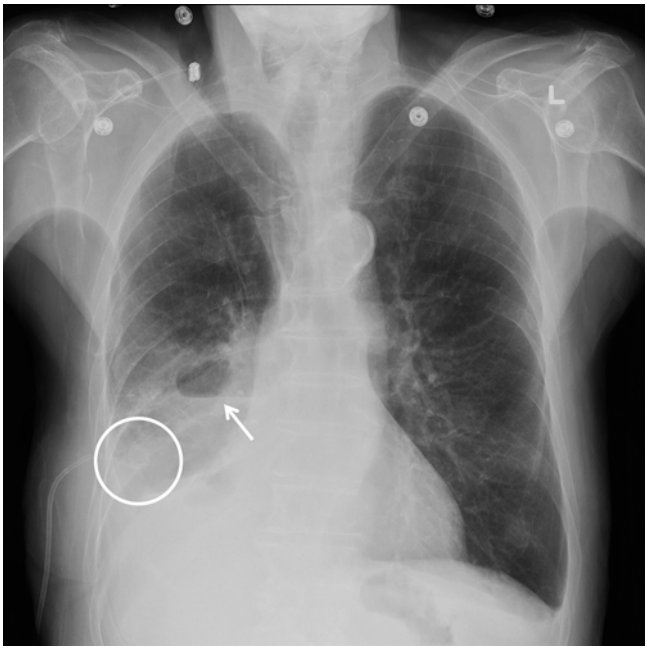

Fig. 11.4 Chest radiograph of patient with a large right-sided complex collection with an air-fluid level (*solid arrow*) and a pig tail catheter in appropriate position (*circle*)

Post-procedure Imaging and Procedural Outcomes

Post-procedure imaging (plain chest X-ray or CT scan) is targeted toward identifying developing complications following the procedure and assessing technical success of the procedure (Fig. 11.4). Procedural outcome is characterized by acute and delayed symptom improvement and reduction in fluid collection volume on imaging [2, 10].

Vascular Interventional Radiology Procedures

There are multiple interventional radiology procedures focusing on pathologies of the thoracic vasculature. These procedures are focused primarily on the treatment of hemoptysis, pulmonary arteriovenous malformations, pseudoaneurysms, and superior vena cava (SVC) obstruction. Common vascular thoracic interventions include bronchial artery embolization for hemoptysis and pulmonary artery arteriovenous malformation (AVM) embolization. Summarized here is the management for hemoptysis using bronchial artery embolization and embolization for pulmonary artery AVMs [2, 10].

Hemoptysis and Bronchial Artery Embolization

Hemoptysis is defined as coughing up blood originating from the lower respiratory tract and can be differentiated into minor (<30 mL), moderate to severe (30–300 mL), and massive (>300 mL) based on the quantity of expectorated blood. Patients with massive hemoptysis (>300 mL per 24 h) have high mortality primarily due to the risk of asphyxiation and aspiration. Bleeding may originate from both small and large lung vessels [2, 10, 13, 14].

Infectious causes of hemoptysis include abscess, chronic bronchitis, bronchiectasis, pneumonia, fungal infections, and tuberculosis. Oncologic causes of hemoptysis include primary or metastatic pulmonary malignancy. Vascular causes of hemoptysis include pulmonary vasculitis, arteriovenous malformations, and pulmonary artery aneurysms. Ninety percent of cases of massive hemoptysis requiring intervention originate from the bronchial arteries [15].

Pre-procedural Imaging and Diagnosis

Bronchoscopy is useful as a first-line diagnostic tool to diagnose active hemorrhage and identify the site of bleeding. Diagnostic imaging modalities for the assessment and characterization of hemoptysis include chest radiographs, CT and CT angiography, and digital subtraction angiography (DSA) [2, 10, 13, 14].

Chest radiography is considered the initial method to evaluate patients with hemoptysis and can help assess focal or diffuse involvement of lung and identify underlying parenchymal and pleural abnormalities but has a very low sensitivity. Bronchoscopy is more effective in localizing bleeding site in moderate to severe hemoptysis cases compared to mild presentations [2, 10, 13, 14].

Compared to bronchoscopy, CT angiography (CTA) scans are equally effective at characterizing site of bleeding and are further able to detect neoplasms or bronchiectasis that may be underlying in patients with hemoptysis. CT and CTA provide a method to comprehensively evaluate the lung parenchyma, airways, and thoracic vasculature as well as develop more detailed and accurate maps of the thoracic vasculature than DSA [2, 10, 13, 14].

DSA is indicated in cases where other diagnostic imaging techniques including CTA have been attempted and endovascular treatment has been attempted but was unsuccessful [2, 10, 13, 14].

Active extravasation is observed in only 10.7 % of examinations [16]. Abnormal bronchial artery diameter (>3 mm) on angiography in conjunction with bronchoscopic findings and clinical correlation is used in addition to observed extravasation to improve sensitivity and specific of localization of bleeding source [16, 17].

Contraindications

Contraindications for this procedure include general contraindications to angiography due to the use of contrast media and angiography for intra-procedural image guidance [2, 10, 13, 14, 17]:

- Uncorrected coagulopathy—this may be due to anticoagulation, vitamin K deficiency, or medical conditions including liver disease, disseminated intravascular coagulation, or platelet deficiency.
- Impaired renal function—the use of radiopaque contrast throughout this procedure leads to risk of contrast-induced nephrotoxicity, and in particular, patient should not be dehydrated prior to receiving contrast. Patients allergic to contrast media should be treated with steroids and antihistamines prior to the procedure.

Procedure

- A brief neurological exam is performed prior to the commencement of the procedure in order to establish a baseline status.
- Under local anesthetic and conscious sedation, a thoracic aortogram is obtained in order to map the bronchial and systemic non-brachial feeding arteries to the bleeding site.
- Common femoral arterial access is the predominant technique for this procedure.
- Brachial artery access can be used in cases of difficult non-bronchial systemic artery contributions [2, 10, 17, 19].
- A reverse-curved or forward-looking 5, 5.5, or 6 French gauge selective catheter is guided through the common femoral artery into the thoracic aorta and the bronchial artery.
- Using the positioned sheath, microcatheters are threaded through for selective bronchial artery access, and to reduce the risk of nontarget embolization [18].
- It is important to ensure placement of the catheter beyond the origin of the spinal cord arteries to reduce the risk of spinal cord embolization.
- Embolization materials that can be used include gelatin sponges, polyvinyl alcohol particles 350–500 μm in diameter, and cross-linked gelatin microspheres.

Outcomes

Technical success, as characterized by complete embolization of bronchial artery on angiography, occurs in more than 90 % of interventions (Fig. 11.5). Clinical success post-embolization ranges from 73 to 94 % based on post-procedure symptom assessment and clinical follow-up. Clinical failure is usually due to technically inadequate occlusion or poor characterization of bleeding source on initial arteriography. Rate of recurrence of hemoptysis following embolization is very high,

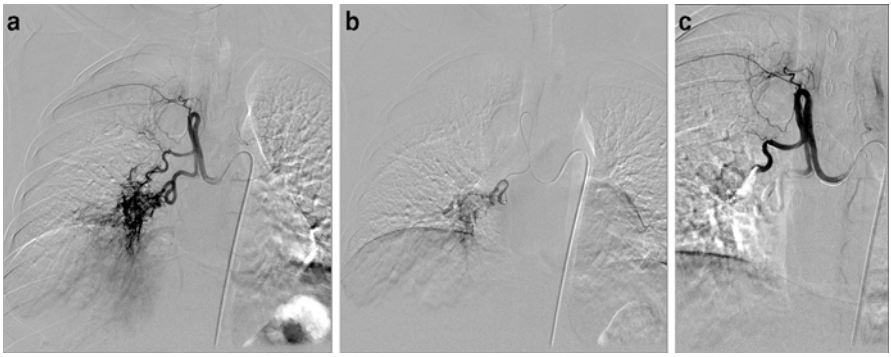

Fig. 11.5 (**a**) Hypertrophied right bronchial artery on angiogram. (**b**) Microcatheter positioned within the right bronchial artery and (**c**) right bronchial artery on angiogram following embolization with angiographic embolization end point visualized

ranging from 10 to 55 % for longer-term follow-up period up to 46 months and depends on patient factors, technical factors, and underlying etiology. Patients with underlying infectious processes leading to hemoptysis (such as aspergillosis and tuberculosis) are at elevated risk for recurrence of hemoptysis [2, 10, 17–19].

Complications

Patients undergoing this procedure are at risk of angiographic complications including:

- Bleeding/bruising at puncture site
- Puncture site infection
- Allergic reaction to contrast media
- Contrast-induced nephropathy
- Myocardial infarction
- Stroke
- Blood vessel damage
- Death (in rare cases)

In addition, patients undergoing this procedure are at risk of embolization complications including:

- Post-embolization syndrome (pleuritic pain, fever, dysphagia and leukocytosis lasting 5–7 days).
- Unintentional, non-target embolization.

Post-embolization syndrome, a condition characterized by pleuritic pain, fever, dysphagia, and leukocytosis, may occur in some patients lasting for 5–7 days. It is managed through symptom relief until resolution. Unintentional, nontarget embolization is the most frequent cause of complications in this procedure including esophageal nontarget embolization leading to transient dysphagia (1–18 %). Chest

pain is a common complication and may occur in 24–91 % of cases. Spinal cord ischemia leading to transverse myelitis is a very severe complication and has been characterized in the literature to occur in 1.4–6.5 % of cases [2, 10, 17–19].

Post-procedure Imaging

Additional diagnostic imaging (CXR or CT scan) is completed if patients develop symptoms prior to discharge. Bronchoscopy may be required in follow-up for symptom assessment [2, 10, 17–20].

Pulmonary Arteriovenous Malformations

Pulmonary arteriovenous malformations (AVMs) are direct connections between pulmonary artery branches and corresponding draining pulmonary veins without corresponding capillary beds. Some pulmonary AVMs may be composed of more than one feeding artery and more than one draining vein, may form a plexus, and may be separated or multichanneled. In pulmonary vasculature, AVMs are primarily congenital but may be acquired secondary to liver cirrhosis, infection, trauma, or malignancy. Approximately 70 % of pulmonary arteriovenous malformations occur in patients with hereditary hemorrhagic telangiectasia (HHT). Pulmonary AVMs may increase in size over time and if left untreated can lead to significant morbidity and mortality. Pulmonary AVMs are a potential source of paradoxical emboli due to the right to left shunt created [2, 10, 21].

Indications

Indications include [2, 10, 21]:

- Symptom management—hemoptysis or hemothorax resulting from aneurysmal sac or vessel wall rupture, epistaxis, dyspnea, congestive heart failure, or fulminant respiratory failure
- Hypoxemia management
- Prevention of hemorrhagic and paradoxical embolization complications
- Feeding vessel larger than 3 mm in diameter
- Pulmonary AVM > 2 cm in diameter

Untreated pulmonary AVMs have been associated with stroke, transient ischemic attacks, brain abscesses, migraine headaches, and seizures secondary to infected and noninfected material emboli from the right to left shunt [2, 10, 21].

Procedure

Helical CT with 3D reconstruction is used to assess the vasculature supplying the AVM. Selective transcatheter embolization is performed on all of the feeding arteries. Using a common femoral vein approach, a catheter is guided into the pulmonary vasculature and into the AVM supplying vessels. Embolization materials used in this procedure are primarily endoluminal coils, but previous studies have assessed the use of detachable balloons or polyvinyl alcohol [2, 10, 21].

Outcomes

Closure rates of pulmonary AVMs have been documented as 98 % in reported literature. Successful embolization of the AVM results in resolution of the right to left shunt. Multiple interventions are necessary in 20–40 % of cases. Major issues with failure occur with incomplete characterization of feeding vessels and unrecognized persistent feeding arteries. Recruitment of additional feeding arteries or recanalization of embolized feeding arteries may lead to embolization failure [2, 10, 21].

Complications

Complications include [2, 10, 21]:

- Post-embolization syndrome
- Pulmonary infarction distal to embolization location
- Pleuritic chest pain
- Sepsis
- Retrograde pulmonary embolism
- Paradoxical embolization
- Air embolism—manifesting as angina, bradycardia, transient ischemic episodes, and facial paresthesia

Superior Vena Cava Obstruction

Overview

SVC obstruction (also known as SVC syndrome) is an intrinsic blockage or extrinsic compression of the SVC leading to restriction of venous return to the right atrium (Fig. 11.6). Symptoms related to SVC obstruction may include dyspnea, coughing, and face, neck, upper body, or arm swelling. More severe symptoms may include tachypnea, cyanosis, dilation of the upper body veins, mental status changes, lethargy, syncope, and fluid collection in the arms and face. Untreated SVC

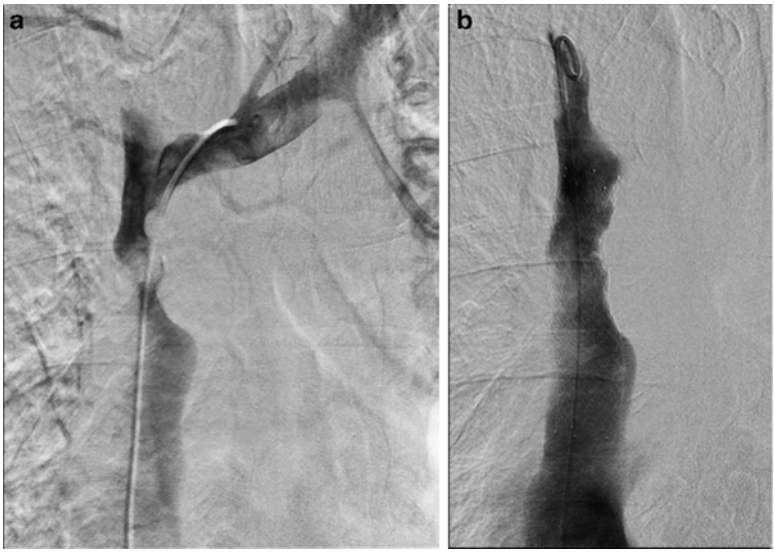

Fig. 11.6 Superior vena cava obstruction with (**a**) catheter placed in the left brachiocephalic vein and (**b**) downstream of the union between the left and right brachiocephalic veins proximal to the heart

obstruction may result in death. It can be caused by extrinsic primary or metastatic tumors or enlarged lymph nodes compressing the superior vena cava, central venous line-related benign stenosis, and postoperative changes causing stenosis [10, 22].

Medical management of SVC obstruction is done using chemotherapy or radiotherapy. Interventional management of SVC obstruction involves balloon angioplasty and stent placement. Balloon angioplasty and stent placement have become the first-line therapy for SVC obstruction [10, 22].

Pre-procedural Imaging

CT scans of the thorax are used for preliminary imaging, assessment of malignancy including metastases and lymph node involvement, and anatomical changes that may be causing obstruction. After clinical diagnosis has been made, degree and extent of obstruction is characterized using venogram at the time of the procedure.

Indications and Contraindications

Stenting has become the first-line therapy for SVC syndrome due to its immediate onset of effect and noninterference with further treatment of thoracic malignancies. The following must also be considered:

- Patients who have previously received the maximum radiation dose
- Primary and secondary malignant tumors located in the mediastinum

Relative contraindications include:

- Preterminal patient status
- Extensive chronic venous thrombosis
- Endoluminal tumor growth
- Upper limb paralysis
- Inability to undergo fluoroscopy and DSA

Absolute contraindications include unresolvable severe cardiac or coagulation disorders.

Outcomes

Outcome of SVC obstruction stenting and balloon angioplasty is based on post-intervention endoluminal diameter and resolution of clinical symptoms. Overall complete or partial symptom relief was achieved in 68–100 % of cases of SVC obstruction due to malignancy across several studies [10]. One in-depth study assessed rates of complete symptom response within 72 h of treatment [22]:

- 66 % of patients with headache
- 81 % of patients with jugular engorgement
- 76 % of patients with collateral venous network on DSA
- 39 % of patients with dyspnea and 100 % of patients with edema

Average patient survival after stenting was approximately 6 months [22].

Complications

The complication rates of stenting for SVC obstruction are very low but may include:

- Stent migration
- Hemorrhagic complications after local thrombolysis
- Incomplete stent opening
- Thrombus formation
- Pulmonary embolism
- Vascular perforation
- Infection

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