Multimodality Imaging of Pulmonary Hypertension

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PULMONARY HYPERTENSION

Elevated pulmonary arterial pressures are the result of a spectrum of diseases that have been classified into 5 categories by the World Symposium on Pulmonary Hypertension.1 The finding of pulmonary hypertension (PH) is usually the first step in a multidisciplinary workup to diagnose the underlying cause, as different etiologies have different treatment algorithms and outcomes. Diagnostic imaging plays a key role in not only the initial evaluation of a patient with PH, but also to assess disease progression or treatment response.

In trying to discover the underlying cause of PH, the diagnostic radiologist often must act as a detective. While some findings, such as varying degrees of enlargement of the pulmonary trunk and remodeling of the right heart, are ubiquitous in patients with PH, it is often the more subtle findings that can help elucidate the cause. These findings may be isolated to the lung parenchyma or may involve the pulmonary or systemic vasculature, heart, or mediastinum. The purpose of this article is to review the various findings of PH on computed tomography (CT) and ventilation/perfusion (V/Q) scans that can help one to differentiate between the various etiologies.

ASSESS THE PULMONARY VASCULATURE

When evaluating the pulmonary vasculature, there are various findings suggestive of PH that are common between the various causes. These include pulmonary artery (PA) enlargement, PA-to-aorta ratio >1, and an increased segmental artery-to-bronchus ratio (Figure 1).2 While 3 cm is often used as a normal

Figure 1: Idiopathic pulmonary arterial hypertension (PAH) in a 35-year-old woman. (A) Axial maximum intensity projection (MIP) image shows a dramatically enlarged pulmonary artery (PA) measuring 4.6 cm. This is much larger in size than the adjacent ascending aorta (Ao). (B) Examination of the segmental PAs (black arrows) show that they are much larger in diameter compared to the adjacent segmental bronchi (white arrows) consistent with pulmonary hypertension (PH). (C) Axial MIP through the lower lobes shows relatively rapid tapering of the PAs as they extend toward the periphery of the lung (white arrows). Some of the vessels have a corkscrew appearance common in cases of severe PH (black arrows). (D) Axial image through the heart shows pronounced thickening of the right ventricular (RV) wall (white arrow) due to RV hypertrophy. There is flattening of the interventricular septum (black arrow) toward the left ventricle (LV) due to increased RV pressures. The right atrium (RA) is also larger than the left atrium (LA) due to PH.

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cutoff value for PA size, it is by no means a diagnostic finding as studies have found no direct correlation between PA diameter and mean PA pressure.³ Multiple factors can affect PA size and include body mass index, systemic hypertension, diabetes, age, and underlying cardiovascular disease.⁴ Therefore, if the main PA measures > 3 cm, one should also look at size of the segmental arteries and adjacent bronchi. While a segmental PA-to-bronchi ratio greater than 1:1 is weakly correlated with elevated PA pressures,³ the presence of both parameters has a high specificity for the diagnosis of PH.⁵ An alternative and often preferred method is to assess the diameters of the main PA and the aorta. A ratio > 1 is commonly associated with PH.⁵,⁶

It is extremely important to recognize chronic thromboembolic PH (CTEPH) as a cause of PH since invasive treatments can be curative.⁷ While disease involving the central vasculature can be quite conspicuous (Figure 2), with large chronic clots layering in and sometimes obliterating the lumen of the main and lobar arteries, disease isolated to the peripheral vasculature can be quite subtle. Close inspection of the segmental and subsegmental pulmonary vasculature on pulmonary angiography CT scans can show abrupt occlusion of PAs with a “pouch” defect, luminal irregularities with eccentric wall thickening, abrupt caliber change (often due to recanalization), and webs or bands (Figure 3).⁸-¹⁰

Pulmonary arterial hypertension (PAH, Group 1) includes idiopathic PAH, heritable PAH, drug/toxin-induced PAH, and PAH associated with connective tissue disease, human immunodeficiency virus (HIV) infection, portal hypertension, congenital heart disease, and schistosomiasis.¹ In severe longstanding PAH, in situ thrombus and calcified atherosclerosis along the walls of the PAs may develop due to extremely high pressures (Figure 4). Even among experts, these findings can be mistaken for CTEPH, and given the differences in treatment, this distinction is quite important. One method to distinguish is to evaluate the morphology of the more peripheral vessels. While both can give rise to “corkscrew” appearing vessels and/or peripheral pruning of the vasculature, in PAH the findings are diffuse (Figure 1), while in CTEPH there are often discrete areas of lobar, segmental, and subsegmental obliteration (Figure 2). V/Q scan or dual-energy CT angiography can often help differentiate. In PAH, one will see heterogeneous regional perfusion without mismatch on V/Q scan or occlusive filling defects on CT scan (Figure 4). In CTEPH, V/Q mismatches correspond to vascular territories, and
discrete occlusive lobar, segmental, and subsegmental filling defects can often be seen on CT (Figure 5). Another method of differentiation is the evaluation of the pulmonary parenchyma, as discussed below, which show distinct changes associated with the underlying pathophysiology.

Another less common mimic of CTEPH is a PA sarcoma. Differentiation between these two entities can be difficult, which is highlighted by the fact that most PA sarcomas are initially misinterpreted as intravascular thrombus. However, certain findings, if present, are suggestive of a sarcoma, including a soft tissue mass nearly filling and potentially expanding the lumen of the pulmonary trunk, left PA, or right PA with protrusion of the proximal end of this mass towards the right ventricular (RV) outflow tract (Figure 6). The ends of the soft tissue mass are often curvilinear. The mass can demonstrate enhancement on portal-venous phase of imaging. Positron emission tomography-CT and magnetic resonance imaging may need to be performed to differentiate in complex cases.

**EVALUATE THE HEART AND SYSTEMIC VASCULATURE**

In addition to remodeling the PAs, chronically elevated pulmonary pressures cause remodeling of the right heart. Findings such as RV hypertrophy (free wall thickness >4 mm), RV dilatation (>1:1 ratio between RV and left ventricle diameter on axial images), and flattening or leftward deviation of the interventricular septum are associated with increased pulmonary pressures (Figures 1 and 2). PH can lead to RV failure, which is often associated with dilation of the inferior vena cava with reflux of contrast into the hepatic veins (Figure 7). Prolonged hepatic congestion can lead to cirrhosis.

The presence of a dilated right heart (with or without hypertrophy) should always prompt a careful search for an undiagnosed intracardiac or extracardiac...
shunt as the cause of PH (Figure 7). Evaluation of the cardiac valves, even on a study performed without cardiovascular electrocardiogram gating, should be performed. Mitral stenosis, which manifests as thickening and calcification of the valve leaflets with severe left atrial dilation, can lead to PH (Figure 8). The aorta and branch vessels should also be assessed for irregularities, such as areas of stenosis and aneurysmal dilation, that may signify an underlying vasculitis as the cause of the PH (Figure 9).

**Figure 7:** 67-year-old woman presenting to the emergency department with shortness of breath. (A) 4-chamber image through the heart from a pulmonary embolism computed tomography angiography shows a dilated right heart and right lobe pulmonary artery (black arrow) consistent with pulmonary hypertension. A defect is present in the superolateral and posterior aspect of the interventricular septum consistent with a sinus venosus atrial septal defect (SV-ASD). Incidental note is made of a left-sided superior vena cava (LSVC). (B) Sagittal oblique image through the heart shows a dilated right atrium (RA) and reflux of contrast into a distended inferior vena cava (IVC) due to elevated right heart pressures. The right-sided superior vena cava (SVC) is mildly enlarged centrally. An SV-ASD (black arrow) is present along the inferior aspect of the SVC near its junction with the RA allowing for communication between the right heart and the left atrium (LA). The right inferior pulmonary vein (PV) drains into the LA. The right superior pulmonary vein (white arrows) anomalously drains into the SVC (white arrow) consistent with a partial anomalous pulmonary venous return. The 2 anomalies coexist in the majority of cases of a SV-ASD.

**Figure 8:** Longstanding mitral stenosis (MS) leading to pulmonary hypertension in a 70-year-old woman. (A) Axial computed tomography image shows a dilated main pulmonary artery (PA). There is diffuse ground glass opacity with septal thickening due to pulmonary edema. (B) Axial image through the heart shows a dilated left atrium with thickening of the mitral valve leaflets (white arrows). (C) Doppler image from an echocardiogram shows a high velocity jet flowing from the left atrium (LA) into the left ventricle (LV) through a severely stenotic mitral valve with a markedly reduced opening area (white arrow).

**Figure 9:** Axial computed tomography in a 20-year-old woman with Takayasu’s arteritis shows marked narrowing of the left pulmonary artery (white arrow) due to vasculitis. The right pulmonary artery was also narrowed. Circumferential thickening of the wall of the aorta (white arrowheads) helps make the diagnosis of a large vessel vasculitis. **ASSESS THE PARENCHYMA**

**Interlobular Septal Thickening**

Interlobular septal thickening is most often seen in PH due to left heart failure. Smooth septal thickening represents the increased interstitial congestion/edema of the pulmonary veins and lymphatics related to increased left atrial pressures (Figure 8). Ultimately, the passive backward transmission of increased left atrial filling pressures leads to the pulmonary vascular remodeling and right heart failure associated with PH. Irregular septal thickening can be seen along with reticulation with fibrosis, and nodular septal thickening can be seen with sarcoidosis and lymphangitic disease. In the absence of left heart failure/enlargement, interlobular septal thickening associated with PAH is the hallmark of postcapillary congestion seen in patients with pulmonary veno-occlusive disease (PVOD). PVOD is characterized by intimal fibrosis, which leads to the occlusion and narrowing of pulmonary veins from the postcapillary level and beyond. As a consequence, the lymphatic channels within the interlobular septa dilate and become edematous, leading to the
smooth interlobular septal thickening classically seen on CT (Figure 10) and the septal thickening (Kerley B lines) seen on radiographs. In PVOD, smooth interlobular septal thickening is often associated with scattered ground glass opacities, pleural effusions, and mediastinal lymphadenopathy. V/Q scans are regarded as nonspecific for PVOD and can have a wide range of interpretations ranging from normal to findings of “high probability” with mismatched perfusion defects. Although the distinction between PCH and PVOD on imaging can be difficult, septal thickening and pleural effusions are less common in PCH. In PCH, they represent the capillary proliferation within the alveolar walls; however, in PVOD these nodules represent the looplike capillary engorgement seen secondary to pulmonary venous narrowing and stenosis. Given that PCH/PVOD share similar hemodynamic, clinical, and radiographic findings, revised guidelines recommend that PVOD and PCH be combined into a single diagnosis called “PAH with overt features of venous/capillaries (PVOD/PCH) involvement.”

Nodules

In an untreated patient with PAH, the presence of hazy centrilobular nodularity should raise the possibility for pulmonary capillary hemangiomatosis (PCH; Figure 11). These nodules are often diffuse in nature, involve all lobes, and spare the lung periphery. Although the distinction between PCH and PVOD on imaging can be difficult, septal thickening and pleural effusions are less common in PCH. In PCH, they represent the capillary proliferation within the alveolar walls; however, in PVOD these nodules represent the looplike capillary engorgement seen secondary to pulmonary venous narrowing and stenosis. Given that PCH/PVOD share similar hemodynamic, clinical, and radiographic findings, revised guidelines recommend that PAH with PVOD/PCH belong to a subgroup of Group 1 PH (subgroup 1.6) for the spectrum of pulmonary vascular disease known as “PAH with overt features of venous/capillaries (PVOD/PCH) involvement,” as opposed to two distinct entities.

In patients with PAH not related to PVOD/PCH, hazy ground glass centrilobular nodules can occur and can mimic findings seen in PCH (Figure 12). While the nodules in PCH represent...
intravenous injection of crushed oral tablets, usually narcotic pain killers. Excipients, including talc, microcrystalline cellulose, crospovidone, and starch, are insoluble inert filler materials that bind and protect the active drug.26 When the drug is injected, this material embolizes into the pulmonary arterioles, inciting a granulomatous reaction in and around the vessel. As the pulmonary arteriole is in the center of the pulmonary lobule, this granulomatous reaction leads to diffuse ground glass nodules which involve the entire lung from the apices to the bases. In comparison to the centrilobular nodules seen in PAH and PCH, these nodules tend to be small and well defined (Figure 13).

Sarcoidosis is a multisystem disease characterized by noncaseating granulomatous inflammation which often manifests along and within the pulmonary vessels and airways as well as the subpleural interstitium. This inflammation creates small nodules in a perilymphatic distribution which are distinct from the centrilobular nodules seen on PAH and PCH (Figure 14). As discussed below, symmetric mediastinal and hilar lymphadenopathy and perihilar conglomerate fibrotic masses may develop over time. Sarcoidosis may contribute to PH via capillary destruction and alveolar hypoxia/hypoxic pulmonary vasoconstriction in the setting of fibrosis in late-stage (class 4) disease; however, the degree of PH in these patients is out of proportion to the degree of fibrosis in many patients, implicating additional mechanisms of SAPH including pulmonary vascular infiltration/obliteraton by granulomatous inflammation, altered flow dynamics due to lymphadenopathy, and cardiac/extracardiac disease.27,28

Mosaicism
Specific patterns of a mosaic attenuation, defined as regional heterogeneity in pulmonary parenchymal attenuation, are characteristic for certain types of PH. Although any cause of PH can lead to a mosaic attenuation, PAH and CTEPH are the most common.29 Mosaic attenuation, also referred to as “mosaic perfusion,” reflects regional difference in lung perfusion in patients with PH.30 In PAH, mosaicism often manifests as focal perivascular ground glass opacities, or small, scattered areas of increased attenuation often confined to center of the secondary pulmonary lobule.31 (Figure 15). In some instances, the perivascular hyperattenuation can appear as subtle ground glass centrilobular nodules as discussed above.

Compared to the mosaic pattern seen in PAH, the pattern in CTEPH often manifests as larger, regional areas of decreased attenuation that correspond to a vascular territory with associated narrowing or occlusion of the supplying vessel (Figure 15).32,33 In severe cases of CTEPH, in addition to areas of hypoperfusion, segmental or subsegmental areas of hyperperfusion and increased attenuation can be present and reflect...
shunting of blood to these nonoccluded regions. Within these areas of hyperperfusion, the corresponding vasculature is often engorged and increased in size compared to the adjacent bronchus reflecting increased blood flow (Figure 5).

PH due to left heart disease and PH due to lung disease and/or hypoxia are less likely to lead to a mosaic pattern.

These can usually be distinguished on imaging by the presence of ancillary findings, for example, dilated left atrium in the setting of mitral valve disease, presence of severe emphysema, fibrosis, or other lung disease, as discussed below. Therefore, the combination of PA enlargement and mosaic attenuation should prompt a careful search for ancillary findings to help narrow the differential diagnosis.

**Emphysema**

The prevalence of PH in chronic obstructive pulmonary disease (COPD) varies from 50% in mild disease to 70% to 90% in severe disease.34 The pathogenesis of PH in emphysema is multifactorial, resulting from destruction of the pulmonary vascular bed, vascular remodeling, endothelial dysfunction, and thrombosis.34,35 The presence of PH is a poor prognostic indicator, and the 5-year survival rate was 36% for patients with a mean pulmonary arterial pressure >25 mm Hg in one series.36 Over time, PH in patients with emphysema can lead to cor pulmonale and subsequent right heart failure37 (Figure 16).

As emphysema is smoking related, findings are generally upper-lobe predominant. On CT, emphysema can be identified by abnormal lucency with a density less than −950 Hounsfield Units (HU), compared with a normal range −770 to −885 HU for lung parenchyma. The predominant finding of centrilobular emphysema is abnormal lucency in the central portion of secondary pulmonary lobules without a visible wall separating abnormal from normal lung parenchyma; the absence of a surrounding wall differentiates centrilobular emphysema from cystic lung disease. In severe disease, these spaces become extensive and confluent. Paraseptal emphysema typically involves the distal airways and is recognized by its involvement of the subpleural lung. Unlike centrilobular emphysema, the area of focal lucency may be surrounded by a thin wall. An area of paraseptal emphysema >1 cm is termed a bulla. Finally, in panlobular emphysema, there is uniform destruction of the pulmonary lobule; unlike other types of emphysema, panlobular emphysema tends to affect the entire lung uniformly or may be more basal predominant.

V/Q scintigraphy typically demonstrates in homogenous but matched upper lobe ventilation and perfusion...
corresponding to areas of emphysema.\textsuperscript{38} In some cases, a “stripe sign” may be seen, with centrally decreased perfusion and peripherally preserved perfusion, which is specific for centrilobular emphysema in COPD patients.\textsuperscript{39}

**Fibrosis**

Fibrosis is the common terminal stage in multiple interstitial lung diseases. Mechanisms of fibrosis related to growth factor release, fibroblast activation, and alterations to the endothelin system appear to be shared with the pathogenesis of PH.\textsuperscript{40} While nearly any fibrotic lung disease can be associated with PH, those most commonly associated with PH include collagen vascular disease (particularly systemic sclerosis and rheumatoid arthritis), idiopathic pulmonary fibrosis, and sarcoidosis.\textsuperscript{40}

On both chest x-ray and high-resolution CT, fibrosis usually presents as areas of peripheral reticulation with associated volume loss. More severe fibrosis results in pronounced architectural distortion and widening of the airways, known as traction bronchiectasis. Severe fibrosis also results in honeycombing, represented by multilayered 3 mm to 2 cm cysts in a subpleural location. Two specific histologic patterns of lung disease which demonstrate some of these findings are usual interstitial pneumonia (UIP) and nonspecific interstitial pneumonia (NSIP).

A UIP pattern is seen in idiopathic pulmonary fibrosis (Figure 17) in addition to collagen vascular diseases, especially rheumatoid arthritis and scleroderma. This pattern is characterized by subpleural lower-lobe predominant peripheral reticulation, traction bronchiectasis, honeycombing, and extensive volume loss.\textsuperscript{41} NSIP, which is the most common pattern of fibrotic lung disease seen in patients with collagen vascular diseases, usually demonstrates symmetric lower-lobe predominant peribronchiolar ground glass opacity extending toward the periphery with associated reticulation and traction bronchiectasis.\textsuperscript{42} A characteristic feature of NSIP is the presence of subpleural sparing, distinguishing it from a UIP pattern (Figure 17). Differentiation between these two patterns can be difficult even for the most experienced radiologist.

Compared to the lower-lobe predominant fibrosis seen in UIP and NSIP, the fibrosis in sarcoid is usually perihilar and upper lobe predominant (Figure 18). Perilymphatic nodules may be visualized in areas adjacent to the fibrosis. Less common parenchymal findings include fibrocystic lesions, which manifest as irregular bronchiectatic and cystic changes with an upper lobe predominance. Pulmonary V/Q scintigraphy is usually noncontributory in these patients, and on occasion, vascular narrowing or occlusion due to surrounding lymphadenopathy or perihilar fibrosis can mimic findings in CTEPH (Figure 18). Gallium single photon emission computed tomography imaging may also play a role in diagnosing sarcoidosis but is beyond the scope of this article.

**MEDIASTINUM**

Careful evaluation of the mediastinum is important in patients undergoing imaging workup for PH, as mediastinal abnormalities may implicate alternative, multifactorial diagnoses. Fibrosing mediastinitis (FM) is a rare but serious—and sometimes fatal—disease with focal granulomatous and diffuse non-granulomatous subtypes; diffuse disease is characterized by florid inflammation and fibrous proliferation within the mediastinum, which results in encasement and extrinsic compression of mediastinal structures including airways and vascular structures.\textsuperscript{43–45} Vascular manifestations most commonly involve the superior
Pulmonary hypertension in fibrosing mediastinitis (FM). (A) Axial oblique image through the left atrium shows a confluent, predominantly calcified soft tissue mass surrounding and compressing the left atrium due to FM. The ostia of the left superior (white arrow), left inferior (white arrowhead), and right superior (not shown) pulmonary veins were completely obstructed by FM. The ostium of the right inferior pulmonary vein is severely narrowed but patent (black arrow). The pronounced pulmonary venous obstruction was the cause of the patient’s severe pulmonary hypertension as evidenced by the markedly enlarged main pulmonary artery (PA) which is much larger than the adjacent ascending aorta (Ao). (B) Axial oblique maximum intensity projection image shows a markedly enlarged main PA. Confluent predominantly calcified soft tissue fills the mediastinum with mild narrowing of the left and right main PAs (white arrows). The patient died a few months after the exam.

Focal/granulomatous FM is most often associated with Histoplasma or tuberculosis infection, with rupture of the encapsulated granuloma thought to trigger an intense fibroinflammatory response in some patients, but diffuse disease can be secondary to myriad causes including trauma, prior radiation therapy, autoimmune disease (eg, rheumatoid arthritis and systemic lupus erythematosus), sarcoidosis, Behçet Disease, sclerosing neoplasm, or may be idiopathic.45

Classically, CT will demonstrate an infiltrative middle mediastinal soft tissue mass with encasement of adjacent structures (Figure 19). Pulmonary arterial abnormalities are typically central in distribution (ie, main, lobar, or segmental) with architectural distortion secondary to fibrosis, inducing irregular arterial narrowing and peripheral soft tissue thickening. Pulmonary venous involvement may be characterized by soft tissue encasement of central pulmonary veins, juxta-ostial or perivenous masslike tissue resulting in stenosis or occlusion, and can be quite dramatic with a pronounced, abrupt “shoulder.” Findings of pulmonary edema, including interlobular septal/peribronchiolar thickening and centrilobular ground-glass opacities, are common in these patients and, when due to PA or vein stenosis, may be geographic depending on the level of obstruction.44 Secondary pulmonary venous infarcts manifest like pulmonary infarcts associated with acute pulmonary embolism, as peripheral, wedge-shaped opacities that may demonstrate central clearing. Scarring secondary to chronic infarcts often demonstrates an atypical distribution with parenchymal bands and peripheral/subpleural reticulation.46 Other CT findings associated with FM include diffuse mediastinal fat stranding/inflammatory change, calcified mediastinal/hilar lymph nodes, and pleural and/or pericardial effusions.

FM can mimic both CTEPH and vasculitis. The geographic areas of perfusion abnormality seen in FM may mimic CTEPH on V/Q scintigraphy, yet this distinction is crucial. While peripheral lobar thrombus in CTEPH may demonstrate a similar appearance, the other characteristic CTEPH findings of weblike filling defects and segmental and subsegmental occlusions will be absent in FM. There is no adequate medical treatment for FM, and currently favored treatment modalities include endovascular angioplasty and/or stenting versus meticulous surgical dissection; however, attempted surgical dissection of the fibrotic rind seen in FM can be extremely difficult and is associated with high perioperative morbidity/mortality.45 If these patients are misdiagnosed as having CTEPH, attempted pulmonary thromboendarterectomy can have devastating consequences. Distinguishing FM from vasculitis is also important, and the presence of alternating tapering/dilation of vessels and/or extrapulmonary vascular structures are highly suggestive of a vasculitis.

Mediastinal involvement with sarcoidosis most typically manifests as relatively symmetric enlargement of hilar and mediastinal lymph nodes with or without concomitant pulmonary parenchymal findings depending on the stage of the disease (Figure 14). Hilar and mediastinal lymphadenopathy is also a common finding in PVOD and is secondary to lymphatic congestion and vascular transformation of the sinuses, intrasinusal hemorrhage, and lymphoid follicular hyperplasia47 (Figure 10). However, PVOD and sarcoid can usually be distinguished from one another through associated parenchymal findings as discussed above.

Finally, specific attention should be given to the esophagus. As mentioned above, FM may result in esophageal compression and upstream dilation. Alternatively, a patulous/dilated esophagus may be seen in the setting of scleroderma, a rare multisystem autoimmune disease that includes PAH in approximately 13% of patients (Figure 12). Interestingly, while patients with PAH related to scleroderma typically have slightly lower mean pulmonary arterial pressure compared to patients with idiopathic PAH, they have higher morbidity/mortality, poorer response to therapy, and worse outcomes than patients with idiopathic PAH, though the pathophysiology and mechanisms underlying these differences have not been entirely elucidated.48

CONCLUSION
The diagnosis of PH should initiate a multidisciplinary workup to elucidate
an underlying cause. Imaging, especially CT, plays an integral part in the initial evaluation. Careful assessment of the pulmonary and systemic vasculature, heart, lungs, and mediastinum allows for one to piece together various clues and make the correct diagnosis, optimizing patient care.

References

1. Simonneau G, Montani D, Celermajer DS, et al. Haemodynamic definitions and updated clinical classification of pulmonary hypertension. Eur Respir J. 2019;53(1).

2. Kligerman SJ, Henry T, Lin CT, Franks TJ, Galvin JR. Mosaic attenuation: etiology, methods of differentiation, and pitfalls. Radiographics. 2015;35(5):1360–1380.

3. Tan RT, Kuzo R, Goodman LR, Siegel R, Haasler GB, Presberg KW. Utility of CT scan evaluation for predicting pulmonary hypertension in patients with parenchymal lung disease. Medical College of Wisconsin Lung Transplant Group. Chest. 1998;113(5):1250–1256.

4. Truong QA, Massaro JM, Rogers IS, et al. Reference values for normal pulmonary artery dimensions by noncontrast cardiac computed tomography: the Framingham Heart Study. Cite Cardiovascular Imaging. 2012;5(1):147–154.

5. Devaraj A, Wells AU, Meister MG, Corte TJ, Wells SJ, Hansell DM. Detection of pulmonary hypertension with multidetector CT and echocardiography alone and in combination. Radiology. 2010;254(2):609–616.

6. Ng CS, Wells AU, Padley SP. A CT sign of chronic pulmonary arterial hypertension: the ratio of main pulmonary artery to aortic diameter. J Thorac Imaging. 1999;14(4):270–278.

7. Jenkins DP, Madani M, Mayer E, et al. Surgical treatment of chronic thromboembolic pulmonary hypertension. Eur Respir J. 2013;41(3):735–742.

8. Sherrick AD, Swensen SJ, Hartman TE. Mosaic pattern of lung attenuation on CT scans: frequency among patients with pulmonary artery hypertension of different causes. AJR Am J Roentgenol. 1997;169(1):79–82.

9. Wittram C, Kalra MK, Maher MM, Greenfield A, McCloud TC, Shepard JA. Acute and chronic pulmonary embolism: angiography-CT correlation. AJR Am J Roentgenol. 2006;186(6 Suppl 2):S421–S429.

10. King MA, Ysrael M, Bergin CJ. Chronic thromboembolic pulmonary hypertension: CT findings. AJR Am J Roentgenol. 1998;170(4):955–960.

11. Gan HL, Zhang QJ, Huang XY, Yu W. The wall eclipsing sign on pulmonary artery computed tomography angiography is pathognomonic for pulmonary artery sarcoma. PLoS ONE. 2013;8(12):e83200.

12. Bandypadhyay D, Panchabhai TS, Bajaj NS, Patil PD, Bunte MC. Primary pulmonary artery sarcoma: a close associate of pulmonary embolism-20-year observational analysis. J Thorac Dis. 2016;8(9):2592–2601.

13. Peña E, Dennie C, Veinot J, Muñiz SH. Pulmonary hypertension: how the radiologist can help. Radiographics. 2012;32(1):9–32.

14. Arivam G, Cohen D, Steinvil A, et al. Significance of reflux of contrast medium into the inferior vena cava on computerized tomodiographic pulmonary angiogram. Am J Cardiol. 2012;109(3):432–437.

15. Ajala Jaramillo F, Gutierrez FR, Díaz Telli FG, Yevens Aravena S, Javidan-Nejad C, Bhalla S. Approach to pulmonary hypertension from CT to clinical diagnosis. Radiographics. 2018;38(2):357–373.

16. Frazier AA, Franks TJ, Mohammed TL, Ozbudak IH, Galvin JR. From the archives of the AFIP: pulmonary veno-occlusive disease and pulmonary capillary hemangiomatosis. Radiographics. 2007;27(3):867–882.

17. Resten A, Maitre S, Humbert M, et al. Pulmonary hypertension: CT of the chest in pulmonary venoocclusive disease. AJR Am J Roentgenol. 2004;183(1):65–70.

18. Montani D, Achouh L, Dorfmüller P, et al. Pulmonary veno-occlusive disease: clinical, functional, radiologic, and hemodynamic characteristics and outcome of 24 cases confirmed by histology. Medicine (Baltimore). 2008;87(4):220–233.

19. Seferian A, Helal B, Jaïs X, et al. Ventilation/perfusion lung scan in pulmonary venoocclusive disease. Eur Respir J. 2012;40(1):75–83.

20. Corte TJ, Wells AU, Nicholson AG, Hansell DM, Wort SJ. Pulmonary hypertension in sarcoidosis: a review. Respir Med. 2011;16(1):69–77.

21. O’Keefe MC, Post MD. Pulmonary capillary hemangiomatosis: a rare cause of pulmonary hypertension. Arch Pathol Lab Med. 2015;139(2):274–277.

22. Simonneau G, Montani D, Celermajer DS, et al. Haemodynamic definitions and updated clinical classification of pulmonary hypertension. Eur Respir J. 2019;53(1).

23. Szumtowicz M, Kacprzak A, Burakowska B, et al. Centrilobular nodules in high resolution computed tomography of the lung in IPAH patients—preliminary data concerning clinical-correlation. Pneumol Alergel Pol. 2016;84(5):265–270.

24. Devaraj A, Hansell DM. Computed tomographic signs of pulmonary hypertension: old and new observations. Clin Radiol. 2009;64(8):751–760.

25. Nolan RL, McAdams HP, Sporn TA, Roggli VL, Tapson VF, Goodman PC. Pulmonary cholesterol granulomas in patients with pulmonary artery hypertension: chest radiographic and CT findings. AJR Am J Roentgenol. 1999;172(5):1317–1319.

26. Nguyen VT, Chan ES, Chou SH, et al. Pulmonary effects of i.v. injection of crushed oral tablets: “excipient lung disease”. Eur Respir J. 1999;166(6):1371–1377.

27. Chauvat A, Naeije R, Weitzenblum E. Pulmonary hypertension in COPD. Eur Respir J. 2008;32(5):1371–1385.

28. Shijaat A, Bajwa AA, Cury JD. Pulmonary hypertension secondary to COPD. Pulm Med. 2012;2012:203952.

29. Oswald-Mammesser M, Weitzenblum E, Quoix E, et al. Prognostic factors in COPD patients receiving long-term oxygen therapy. Importance of pulmonary artery pressure. Chest. 1995;107(5):1193–1198.

30. MacNee W. Pathophysiology of cor pulmonale in chronic obstructive pulmonary disease. Part One. Am J Respir Crit Care Med. 1994;150(3):833–852.

31. Sinzinger H, Rodrigues M, Kummer F. Ventilation/perfusion lung scintigraphy. Multiple applications besides pulmonary embolism. Hell J Nucl Med. 2013;16(1):50–55.

32. Mortensen J, Berg RMG. Lung scintigraphy in COPD. Semin Nucl Med. 2019;49(1):16–21.

33. Behr J, Ryu JH. Pulmonary hypertension in interstitial lung disease. Eur Respir J. 2008;31(6):1357–1367.

34. Raghu G, Remy-Jardin M, Myers JL, et al. Diagnosis of idiopathic pulmonary fibrosis. An official ATS/ERS/JS/ALAT Clinical Practice Guideline. Am J Respir Crit Care Med. 2018;198(5):e44–e68.

35. Kligerman SJ, Groshong S, Gall N, Marrinan MT, Deshpande R, Desai SR. Fibrosing mediastinitis and occlusion of pulmonary veins
after radiofrequency ablation. *Ann Thorac Surg*. 2009;88(5):1674–1676.
44. Seferian A, Steriade A, Jaïs X, et al. Pulmonary hypertension complicating fibrosing mediastinitis. *Medicine (Baltimore)*. 2015;94(44):e1800.
45. Rossi SE, McAdams HP, Rosado-deChristenson ML, Franks TJ, Galvin JR. Fibrosing mediastinitis. *Radiographics*. 2001;21(3):737–757.
46. Kwon MR, Lee HY, Cho JH, Um SW. Lung infarction due to pulmonary vein stenosis after ablation therapy for atrial fibrillation misdiagnosed as organizing pneumonia: sequential changes on CT in two cases. *Korean J Radiol*. 2015;16(4):942–946.
47. Thomas de Montpréville V, Dulmet E, Fadel E, Dartevelle P. Lymph node pathology in pulmonary veno-occlusive disease and pulmonary capillary haemangiomatosis. *Virchows Arch*. 2008;453(2):171–176.
48. Fisher MR, Mathai SC, Champion HC, et al. Clinical differences between idiopathic and scleroderma-related pulmonary hypertension. *Arthritis Rheum*. 2006;54(9):3043–3050.