Radiological Reasoning: 
**Pulmonary Embolism—Thinking Beyond the Clots**

**Abstract**

**Objective**

We discuss the CT findings in a case of pulmonary embolism complicated by paradoxical embolism in a patient with a patent foramen ovale and atrial septal aneurysm.

**Conclusion**

When confronted with a case of pulmonary embolism on CT, besides evaluating the extent of pulmonary artery occlusion, the radiologist should examine the cardiovascular system to identify any unsuspected underlying or associated conditions.

**Case History**

A 60-year-old woman with no significant medical history had resection of a 5-cm non–small cell lung carcinoma of the left lower lobe. This required a pneumonectomy because the tumor encased the left pulmonary artery. Two days after surgery, while attempting to ambulate, the patient became acutely short of breath and hypoxic. Due to the clinical suspicion for pulmonary embolism, CT pulmonary angiography was performed (Fig. 1). (At this point, if the abstract has not been reviewed, we encourage the reader to examine the CT images to formulate a diagnosis before proceeding further.)

**CT**

The CT scan shows subcutaneous emphysema with air and fluid in the left pneumonectomy space. There is a central area of hypopattenuation in the interlobar branch of the right pulmonary artery and in the pulmonary artery to the right middle lobe. Multiple segmental pulmonary arterial filling defects are also present in the right lower lobe. The atrial septum appears deformed with curvature convex toward the left atrium. In the upper abdomen, there is a large wedge-shaped area of hypopattenuation in the spleen and a small subtle area of decreased enhancement in the medial aspect of the superior pole of the left kidney.

**Expert Discussion (Dr. Maldjian)**

The left-sided subcutaneous emphysema and air and fluid in the left pneumonectomy space are expected postoperative findings and do not require further discussion. The filling defects in the pulmonary vessels represent pulmonary emboli. Normally, the short-axis diameter of the right ventricle is about equal to that of the left ventricle. In this case, the right ventricle is dilated compared with the left ventricle. This finding on CT in association with pulmonary embolism may indicate right ventricular dysfunction secondary to the acute elevation of pulmonary artery pressure [1]. The right atrium is also dilated, which is probably due to the elevated right-sided cardiac pressures.
The large wedge-shaped defect in the spleen and the small low-attenuation area in the superior pole of the left kidney represent infarcts. These findings in a patient with pulmonary embolism indicate paradoxical embolism. Paradoxical emboli are most commonly caused by an intracardiac communication between the systemic and pulmonary circulations. Patent foramen ovale and atrial septal defect are the two most common cardiac abnormalities associated with paradoxical emboli [2]. Therefore, we should now scrutinize the image through the cardiac chambers. The atrial septum is bulging abnormally toward the left atrium. This finding is consistent with an atrial septal aneurysm (ASA). Bowing of the ASA toward the left atrium indicates that at the instant the image was obtained the pressure in the right atrium exceeded that in the left atrium. This difference in pressure can be transient, related to the phase of the cardiac cycle, but in this case likely reflects acute elevation of the right-sided cardiac pressures.

The significance of an ASA is its association with patent foramen ovale (PFO). Approximately 70% of patients with an ASA also have a PFO [3]. Thus, we can now postulate a diagnosis that

**Fig. 1**—60-year-old woman who developed acute dyspnea and hypoxia 2 days after left pneumonectomy. Images are from CT pulmonary angiography. **A–D**, CT images at level of right interlobar artery (**A**), at level of cardiac chambers (**B**), through upper abdomen (**C**), and at level of superior pole of left kidney (**D**).
explains all of the CT findings. The pulmonary embolism caused elevation of the right-sided intracardiac pressures that resulted in increased right-to-left shunting through a PFO, thereby predisposing the patient to paradoxical emboli.

**Clinical Management**

After the CT examination, the patient received IV infusion of heparin for systemic anticoagulation. Vascular sonography of the lower extremities performed 2 days later was negative for deep venous thrombosis. Because swelling and erythema of the patient’s left arm were noted by the clinical service, vascular sonography of the left upper extremity was also performed, which revealed thrombosis of the cephalic vein extending into the left subclavian vein. The thrombophlebitis was likely a complication from IV cannulation and was deemed the source of the pulmonary emboli.

Transthoracic and transesophageal echocardiography was performed 6 days after CT. An ASA was seen on the transesophageal study (Figs. 2A and 2B), although it was not visible on the transthoracic study. The transesophageal study obtained with saline used as contrast material also confirmed the presence of a PFO (Fig. 2C). No intracardiac thrombi were present. Right ventricular function was normal. The patient recovered uneventfully and was discharged from the hospital after converting to oral warfarin to continue anticoagulation. The final diagnosis was pulmonary embolism and paradoxical embolism with PFO and ASA.

**Expert Discussion (Dr. Maldjian)**

In most cases, thrombi from the lower extremities are the source for pulmonary emboli, and it is rare to encounter a patient with pulmonary embolism from clots in the upper extremity. Although a
negative sonography examination of the lower extremities does not completely exclude lower extremity veins as a source of emboli, the known thrombus in the upper extremity was the most likely source in this patient. Because the patient had only one lung, it would not require a large amount of embolized clot from the thrombus in the subclavian vein to result in significant compromise of the pulmonary circulation. The patient might also have been at increased risk for thrombophlebitis because a hypercoagulable state is associated with malignancy [4].

The fact that the ASA was visible on only the transesophageal echocardiogram is not surprising because ASAs are commonly missed on a transthoracic study alone [3]. Normal right ventricular function at the time of echocardiography given the appearance on CT likely reflects a good therapeutic response. On echocardiography, the diagnosis of PFO is made using agitated saline (saline containing microbubbles of air) as a sonography contrast agent. The saline is injected IV, and the sonographer looks for passage of microbubbles from the right atrium to the left atrium through the atrial septum. The patient can be asked to cough or bear down (Valsalva maneuver) during the injection; these actions transiently elevate right atrial pressure and increase the amount of shunting through a PFO [5].

Commentary

A definitive diagnosis of paradoxical embolism requires detection of thrombus lodged in the intracardiac defect, most commonly right atrial thrombus crossing a PFO. Such direct observation is rare and is usually limited to sporadic echocardiographic reports [6]. In clinical practice the diagnosis of paradoxical embolism is usually presumptive and requires detection of the following three elements: first, systemic embolism without an apparent source in the left heart or proximal arterial tree (no evidence of atrial fibrillation or severe atherosclerosis of the thoracic aorta); second, venous thrombus or pulmonary embolus as an embolic source; and, third, right-to-left shunting through an abnormal communication between the right and left circulations associated with paradoxical embolism. Pulmonary embolism in the setting of a coexistent PFO increases the risk of paradoxical embolism due to elevated right-sided cardiac pressure increasing right-to-left shunting through the PFO [14]. It has been shown that right-to-left shunting through a PFO is increased in acute pulmonary embolism even in hemodynamically stable patients without preexisting cardiopulmonary disease [15]. In their a study of patients with acute major pulmonary embolism, Konstantinides et al. [6] found right-to-left shunting through a PFO to be an independent predictor of adverse outcome. In that study, those patients with a PFO had a significantly higher incidence of death (33% vs 14%) and ischemic stroke (13% vs 2.2%) than those without a PFO [6].

Therapeutic options for paradoxical embolism associated with PFO include anticoagulation, thrombectomy, placement of an inferior vena cava filter (if the source for embolism is from the lower extremity), and closure of the PFO [16]. Recurrent paradoxical embolism in the presence of a PFO and ASA is considered an unequivocal indication for PFO closure [10]. Closure of a PFO can now be accomplished with devices implanted percutaneously [17].

When confronted with a case of pulmonary embolism on CT, besides identifying the extent of pulmonary artery occlusion, the radiologist should examine the cardiovascular system for any associated abnormalities. Dilatation of the right ventricle and interventricular septal shift toward the left ventricle are associated with right ventricular dysfunction secondary to pressure overload. Other signs of pressure overload of the right heart include enlargement of the right atrium and the inferior vena cava [18]. Patients with right ventricular dysfunction after pulmonary embolism have a higher mortality rate than those with normal right ventricular function even if hemodynamically stable at presentation [19, 20]. Therefore, right ventricular dysfunction in patients with pulmonary embolism places them at increased risk and may be an indication for aggressive intervention, such as thrombolytic therapy, as opposed to anticoagulation alone [21].

A PFO on CT pulmonary angiography can manifest as decreased enhancement of the pulmonary artery with early enhancement of the thoracic aorta from augmentation of right-to-left shunting through the defect caused by deep inspiration [22] (although this was not present in our patient). Significant deviation of the atrial septum might indicate an ASA, and as we have seen, this finding should also raise suspicion for a possible coexisting PFO. The cardiac chambers...
and systemic arteries should also be scrutinized because paradoxical embolism can have characteristic findings on CT [23–25].

In conclusion, we have presented a case of pulmonary embolism complicated by paradoxical embolism in a patient with an ASA and PFO. Although the diagnosis of pulmonary embolism on CT may be straightforward, it is essential that the radiologist examine the remainder of the cardiovascular system for ancillary findings to diagnose unsuspected underlying conditions. The radiologist should look and think beyond the pulmonary clots.

References

25. Oliver TB, Reid JH. Thoracic aortic dissection that wasn’t: CT demonstration of probable paradoxical embolus secondary to unsuspected pulmonary embolus. Br J Radiol 1997; 70:840–842