

worsens when the sudden elevation in right atrial pressure causes right-to-left shunting across the foramen.

The classic symptoms of acute PE are sudden onset of dyspnea and pleuritic chest pain. Additional symptoms include anginal chest pain from right ventricular ischemia, hemoptysis from pulmonary infarction, and syncope or presyncope from massive PE with acute right ventricular failure (cor pulmonale). The most common physical findings are tachypnea and tachycardia. Additional physical findings include a right ventricular lift, inspiratory crackles, a loud pulmonary component of the second heart sound, expiratory wheezing, and a pleural rub. Symptoms and signs of proximal DVT are present in 10% to 20% of patients. Arterial blood gas analysis often reveals hypoxemia, respiratory alkalosis, and a high alveolar-to-arterial oxygen tension gradient. However, normal arterial blood gas values do not exclude the diagnosis.

The most common finding with ECG analysis is sinus tachycardia. Atrial fibrillation, premature atrial contraction, and supraventricular tachycardia are less common. Other ECG changes suggest acute right ventricular strain. These include the S1-Q3-T3 pattern, a new right bundle branch block or right axis deviation, and P-wave pulmonale. However, these findings are present in only 30% of patients even with massive PE. Common but nonspecific abnormalities on chest radiographic studies include atelectasis, pleural effusion, and pulmonary infiltrates. Less common but more specific radiographic findings include Hampton's hump (i.e., wedge-shaped infiltrate in the peripheral lung field), which is indicative of pulmonary infarction, and Westermarck's sign (decreased vascularity).

The plasma D-dimer level is elevated in most patients with PE as a result of activation of the endogenous fibrinolytic system, which is not sufficient to dissolve the clot. Commercially available D-dimer assays have a high sensitivity and negative predictive value but low specificity. Therefore, a normal D-dimer test effectively excludes the diagnosis of PE in patients in whom the clinical suggestion is low or intermediate, but the should not be used to screen patients with high index of suspicion because of the low negative predictive value. Elevated levels of cardiac troponin I and troponin T and other markers of myocardial injury can be found in patients with PE and are indicative of right ventricular dysfunction and a poor prognosis. Similarly, elevated natriuretic peptides, including brain natriuretic peptide (BNP) and N-terminal pro-BNP, have been shown to be predictive of adverse outcomes. In patients with suspected PE, a completely normal  $\dot{V}/\dot{Q}$  scan effectively excludes the diagnosis without further testing. However, fewer than 10% of  $\dot{V}/\dot{Q}$  scans are interpreted as definitively normal. In patients in whom a moderate or high level of clinical probability of PE exists, a high-probability  $\dot{V}/\dot{Q}$  scan has a diagnostic accuracy of 90% to 100%; however, a low or intermediate probability scan is no more helpful than a coin flip.

More recently, multidetector CT angiography has become the imaging modality of choice in patients with acute PE because of its excellent visualization of the pulmonary artery (Fig. 12-5). The resolution of 1 mm or less rivals that of conventional invasive angiography. The speed of newer-generation scanners allows acquisition of all images within a single breath-hold, avoiding respiratory motion artifacts. The overall negative predictive value



**FIGURE 12-5** Spiral chest computed tomographic angiogram shows a large thrombus in the right main pulmonary artery (arrow). (Courtesy Michael Landay, MD, Department of Radiology, University of Texas Southwestern Medical Center, Dallas, Tex.)

of multidetector CT angiography exceeds 99%. A negative CT scan excludes the diagnosis of PE and eliminates the need for further diagnostic testing. The CT scan also permits detection of other pathologic conditions involving the lung parenchyma, pleura, and mediastinal structures. Such pathologic findings may mimic PE and constitute alternative causes of chest pain and dyspnea. Multidetector CT angiography is not yet available at all centers. The requirement for intravenous injection of iodinated contrast material restricts its applicability to those without a history of kidney disease or an allergic reaction to contrast dye.

Figure 12-6 presents an algorithm for the work-up of PE based on current evidence. Echocardiography may directly detect thrombi in the right atrium, right ventricle, or pulmonary artery or may indirectly demonstrate right ventricular dysfunction, signifying the presence of hemodynamically significant emboli. Therefore, it is helpful in diagnosis of PE in patients with hypotension or shock, particularly if multidetector CT is not immediately available. Invasive pulmonary angiography should be reserved for patients for whom noninvasive testing is inconclusive.

Treatment of acute PE includes immediate anticoagulation with UFH, LMWH, or fondaparinux (level A evidence). LMWH and fondaparinux are preferred agents in patients with normal renal function because of the ease of subcutaneous administration and their lower rates of thrombocytopenia. These drugs are excreted by the kidney, so they should be avoided in patients with renal failure, and intravenous UFH should be used instead. Thrombolytic therapy with recombinant tissue-type plasminogen activator (rt-PA) is indicated for patients with either (1) hypotension or shock or (2) right ventricular enlargement or dysfunction from massive PE (level B evidence). Surgical or percutaneous removal of emboli should be considered in patients with massive PE who have contraindications for thrombolytic therapy. After initiation of heparin or fondaparinux, warfarin should be administered. Infusion of heparin or fondaparinux needs to be continued for at least the first 5 days of warfarin therapy until a therapeutic INR of 2 to 3 is reached. Oral rivaroxaban without initial treatment with heparin or fondaparinux is an alternative strategy and is considered to be another option for