Pulmonary embolism (PE) is a major health problem with considerable controversy surrounding the diagnostic approaches and their interpretation. Approximately 600,000 patients per year have clinically significant PE, and 120,000 of them die annually from this disease in the United States without being diagnosed. Deep vein thrombosis (DVT) is the third most common cardiovascular disease after coronary artery disease and stroke; it affects 2 million in the United States per year and gives rise to PE in an estimated 25–30% of affected individuals.

The problems in diagnosis of pulmonary embolism (PE) relate to the nonspecificity of clinical signs and symptoms and to the relatively invasive nature and high costs associated with the most definitive diagnostic procedure, pulmonary angiography. The radionuclide lung scan is used widely because it is safe, readily available, easily performed and highly sensitive for diagnosis of PE. Spiral CT has an increasingly important role in the diagnosis of PE; the radionuclide ventilation/perfusion lung scan (often called the V/Q scan or VIP scan), however, is still considered the first line diagnostic test. This is based on 35 yr of reliable clinical experience in the diagnoses of PE, an abundance of data that have led to the revised PIOPED (Prospective Investigation of Pulmonary Embolism Diagnosis) criteria for interpretation, the almost nonexistent morbidity and the relatively low cost of the VIP scan.
SCANS AND PRIMARY CLINICAL INDICATIONS

I. Ventilation/perfusion lung scan
   ● To diagnose pulmonary embolus
   ● To diagnose recurrence of pulmonary embolus
   ● To predict quantitative residual lung function after planned lung resection surgery

II. AcuTect venous thrombus scan
   ● To diagnose DVT, particularly calf thrombi, usually after inconclusive or nondiagnostic Doppler ultrasound
   ● To distinguish acute from chronic venous thrombotic disease

III. Radionuclide venography
   ● To detect DVT based on an obstruction to deep venous flow and the development of collateral channels

CLINICAL QUESTIONS

1. Does my patient have a pulmonary embolus?  
2. What tests other than the V/P scan are available to diagnose PE?  
3. What is the role of the pretest probability estimate of PE?  
4. How does the clinician proceed if the patient has an intermediate probability scan result?  
5. If the chest x-ray shows an infiltrate or effusion, can the V/P scan diagnose PE?  
6. Should a patient treated for a PE have a follow-up scan? If so, when?  
7. What are the risks of PE, anticoagulation and a V/P scan during pregnancy?  
8. If a postpartum patient has a V/P scan, can she continue to breastfeed?  
9. How much lung function will my patient lose if he/she has a partial lung resection?  
10. Should a V/P scan be obtained to diagnose and quantitate right to left cardiac shunts?  
11. Does my patient have DVT?

PATIENT INFORMATION

I. Ventilation/perfusion lung scan
II. AcuTect venous thrombosis scan
I. VENTILATION/PERFUSION LUNG SCAN

A. Background
The abundant published literature and clinical familiarity with the radionuclide ventilation/perfusion lung scan have led to the following conclusions that are accepted by most pulmonary medicine physicians, angiographers and nuclear medicine physicians: (a) a normal perfusion scan indicates no clinically significant emboli; (b) an abnormal perfusion scan alone is a nonspecific indicator of emboli, but a ventilation/perfusion study showing mismatched abnormalities indicates high probability for pulmonary emboli; and (c) the perfusion scan can guide the selection of sites for angiography or for particular attention on the spiral CT study.

Although the lung perfusion scan (without a ventilation scan) is sensitive for pulmonary embolic disease, its specificity is low. Pulmonary embolus causes segmental perfusion defects, but chronic obstructive pulmonary disease can result in similar findings. The ventilation scan improves the specificity of the lung perfusion scan. Ventilation imaging is most likely to be helpful in patients if existing airway disease involves <50% of the lungs. Interpretation criteria based on mismatched and matched perfusion defects have been established for very low, low, intermediate and high probabilities for PE by two widely quoted authorities: Biello (1979) and PIOPED (1990, revised 1995). In acute PE, the ventilation scan is almost always normal, unless there is superimposed parenchymal or airway abnormality. In chronic PE, there may be secondary ventilation abnormality resulting from the long-standing perfusion deprivation.

B. Radiopharmaceuticals
1. Technetium-99m-macroaggregated albumin (MAA). Technetium-99m-MAA is used for lung perfusion imaging. These particles are too large (mean size 20-40 μm) to pass through a capillary. They are trapped in the capillary bed of the pulmonary arterial circulation, which is the first capillary bed they encounter after peripheral intravenous injection. Usually, about 200,000–700,000 particles of 99mTc-MAA are injected into a peripheral vein, causing embolization of a small fraction of 1% of the pulmonary capillaries fed from the pulmonary arterial system. These particles are removed within hours by enzymatic and macrophage activity, restoring full perfusion/function to the 99mTc-MAA embolized regions. In patients with PE, the scan demonstrates an area of decreased radioactivity corresponding to the decreased flow to the embolized lung. Areas of decreased radioactivity are not specific for PE; they also occur in patients with pneumonia, effusions and emphysema, as well as other lung parenchymal and airway abnormalities.

2. Technetium-99m-DTPA aerosol or xenon-133 gas. Technetium-99m-DTPA aerosol or 133Xe gas is used for the ventilation scan. The xenon is more physi-
ologic, and early images show the wash-in phase, followed by its gradual wash-out from the lungs on the delayed images. Only wash-in (equivalent of a first or single breath of xenon) is obtained with an aerosolized particulate material. The advantage of aerosolized ventilation delivery is that lung ventilation can be imaged in multiple projections, whereas xenon is usually limited to the posterior projection. Xenon’s advantage is that it adds wash-out information, which cannot be obtained using the $^{99m}$Tc-DTPA aerosol. The use of either xenon or aerosol is an institutional preference, and both are considered clinically effective.

C. How the lung V/P scan is performed

The perfusion lung scan is performed by injecting the $^{99m}$Tc-radiolabeled particles (2–5 mCi [80—180 MBq] adult dose) into a peripheral vein and then imaging the lungs in multiple projections. The ventilation lung scan usually precedes the perfusion scan; the patient breathes a small amount of a radioactive gas ($^{133}$Xe, 5–20 mCi [200–750 MBq] adult dose) while being imaged, or the patient inhales $^{99m}$Tc-DTPA–labeled aerosol (~1 mCi [37 MBq] adult dose) and is imaged immediately afterward. The patient usually is imaged while lying supine but may sit upright (after the injection of the perfusion tracer). The V/P scan is performed with conventional scintillation camera planar imaging. A few centers have used the tomographic camera technology of SPECT for perfusion scans to depict the lung anatomic segmental volumes, but no substantive advantages have been documented. The ventilation and perfusion procedures take about 30–60 min.

Quantitative lung scan. The quantitative lung scan is performed exactly as a conventional lung scan, except that the images are computer processed by drawing regions of interest over each lung and over regions corresponding to the lobes within each lung. Ventilation images also can be quantitated, if desired, or the quantitative study may be limited to the perfusion images.

D. Patient preparation

The patient first has a chest x-ray performed to identify pathology that may obviate a much more expensive test; furthermore, the chest x-ray is needed for correlation with the V/P scan. After obtaining the chest x-ray, there is no special preparation for lung V/P studies. The patient can eat and drink fluids, as usual. If the patient has a large pleural effusion, tapping off fluid will result in a better look at the underlying lung, but there should be no undue delays imposed to obtain a needed V/P study.

E. Understanding the report

The report may describe the specific signs and symptoms that triggered the request of a lung scan by the clinician and the patient’s risk factors with a clinical estimate of pretest probability for PE, if suspicion of PE is the reason for the
test. In the report, the nuclear medicine physician describes the procedure, including the radiopharmaceutical dose, the imaging procedure, the findings and locations of perfusion defects and whether there are matching or mismatching ventilation defects or chest x-ray abnormalities. The impression describes the probability of PE as high (Fig. 1), intermediate, low or very low and may incorporate modulation of the scan probability on the bases of clinical pretest assessment, if provided by the clinician (see Table 1).

1. **Mismatched or matched V/P scan.** The terms “mismatched” or “matched” V/P scan refer to an assessment of any region of perfusion abnormality vis a vis its ventilation. A region of lung with abnormal (decreased) perfusion may show normal ventilation (mismatched V/P) or abnormal ventilation (matched V/P). Ventilation is abnormal if images show decreased counts on the initial wash-in images (i.e., slow to wash-in) or increased counts on the wash-out images (i.e., slow to wash-out). Although wash-in images are obtained with all ventilation imaging agents, wash-out images can be obtained only with xenon gas.

2. **Understanding probabilities of PE.** Ventilation/perfusion scans for PE are interpreted as normal or in terms of probabilities (high probability for PE, intermediate [indeterminate] probability or low probability). If the scan is normal, the likelihood of PE approaches zero. The degree of abnormality and the probability is based on the presence of mismatched or matched V/P abnormalities, their sizes and their numbers. Patients with near normal or very low probability scans are least likely to have PE (0–5%), whereas some patients called low probability, particularly patients with underlying lung parenchymal problems (limited to <50% of lung parenchyma), may have a probability of PE ranging from 10% to 20%. High probability indicates 80–100% of patients will have PE (see Table 1). All scans that do not meet criteria for high or low probability interpretations are called indeterminate probability for PE. The clinical estimates of probability of PE can be altered markedly by the V/P scan interpretation: for example, 83% of patients thought to have a low clinical probability for PE actually have PE if they had high probability V/P scans (Table 1).

3. **Quantitative lung scan.** The report describes the percent contribution to global perfusion of each lung. Combined with pulmonary function tests, these quantitative regional lung function studies allow the clinician to predict how much lung function will remain after proposed surgical excision of an entire lung or a part of one. Ventilation can be quantitated similarly.

**F. Potential problems**

1. **False-positives.** Conditions that can mimic high probability PE scans include vasculitis, other rarer conditions such as pulmonary arterial anomalies, i.e., hypoplasias and stenoses, as well as fat emboli. Vasculitis is associated most often with collagen vascular diseases and recent radiation therapy to the chest.
Figure 1. High probability V/Q scan. Ventilation images (above) were performed using $^{133}$Xe gas. They show normal first breath (wash-in, upper left image), except for limited right apical slowed wash-in. The remaining five images show generally homogeneous wash-out of activity from both lungs. The perfusion images (below) performed with $^{99m}$Tc-MAA particles show multiple perfusion defects throughout both lungs, many of which are wedge-shaped and segmental. The perfusion defects are mismatched by normal ventilation.
2. Clinical pretest probability of PE. The clinician’s estimate of pretest probability of PE can be useful for deriving the post-test probability, but it may be difficult to obtain a valid quantitative or semiquantitative clinical pretest probability because standardized criteria for clinical pretest probability for PE do not exist.

3. Interpretations of defect sizes. Interpretations of size of a defect as “moderate” or “small” may at times be difficult and subjective. Differences in estimating sizes of defects may lead to differences in the interpretation of the probability of PE. A high probability scan is defined as two unmatched moderate or large perfusion defects or, if the patient has prior cardiopulmonary disease, four mismatched defects. A defect of “moderate” size means 25–75% of the area of a lung segment. A “large” defect means >75% of a segment. The revised PIOPED criteria suggest that summations of defect size arithmetic equivalents can be used, so that two defects that each are 50% of a segment can be counted as equivalent to a large defect.

4. Widespread ventilatory abnormalities. Widespread ventilatory abnormalities usually would be interpreted as intermediate (or indeterminate) probability for PE. Pulmonary infarction may show matched V/P abnormalities and matched chest x-ray infiltrate, and an intermediate probability interpretation would result.

5. Right to left shunts. When lung perfusion scan particles (20–50 μm) are injected intravenously in patients with large right to left shunts, there is concern about embolization of shunted particles, particularly to the brain. Shunting occurs in proportion to percent of cardiac output that goes to the organ. To minimize embolization, the number of particles injected can be reduced for patients with right to left shunts, particularly small children.

II. ACUTECT VENOUS THROMBUS SCAN
The clinical diagnosis of DVT often is unreliable without objective testing. Most patients with clinical symptoms suggesting possible DVT do not have DVT.
those with DVT, 80% have proximal venous disease (above the popliteal), and 20% have DVT limited to the calves. Proximal disease is associated with PE in 50% of cases. Proximal extension of calf vein thrombosis occurs in 30% of those cases. As many as 23% of PEs have been estimated to derive from calf venous thrombi. Diagnostic approaches for DVT have relied on the clinical presentation, risk factors and symptoms, supplemented with noninvasive tests, primarily Doppler ultrasound. Limitations of the Doppler ultrasound are that it does not distinguish between acute and chronic DVT and does not perform well in diagnosing calf thrombi. A new nuclear medicine study, using AcuTect, images active thrombi and is particularly sensitive for detecting acute thrombi in calves.

AcuTect is $^{99m}$Tc-labeled to a low molecular weight synthetic peptide that binds to receptors on the surface of activated platelets. AcuTect is injected intravenously; it is not immunogenic and not associated with risk of viral contamination. Anticoagulants will not interfere with imaging acute venous thrombosis with this agent.

Imaging of the pelvis, thighs and calves is performed 30 min and 4 hr after injection (Fig. 2). There is no special patient preparation. The patient needs to be able to lie flat on the imaging table for about 30–45 min. Diet and medication routines can be continued as usual.

III. RADIONUCLIDE VENOGRAPHY

Radionuclide venography using $^{99m}$Tc-MAA can be performed in conjunction with routine perfusion lung scanning. The deep venous system of the lower extremities is visualized by sequential scintillation camera images after injection of a radiopharmaceutical into dorsal pedal veins with tourniquets tied proximally to occlude superficial veins. DVT is indicated by nonfilling of all or a portion of the deep venous system, by filling of abnormal collateral vessels or by the delayed clearance of the particulate tracer. Ultrasound is much easier to perform, and this test is used rarely.

CLINICAL QUESTIONS

1. Does my patient have a pulmonary embolus?

The clinical signs and symptoms for PE can be so elusive and the consequences of unrecognized PE so serious that if the possibility of PE occurs to the clinician as he/she examines a patient, a V/P scan should probably be obtained.

The V/P lung scan is interpreted as high, intermediate, low or very low probability of PE. High probability V/P scan is strong evidence for instituting appropriate therapy. Even in the face of an estimated low clinical probability, there is still an 83% chance of an underlying pulmonary embolus (Table 1), and most clinicians would consider this sufficiently high odds to treat without an angiogram. Low probability V/P scan is strong evidence against PE, but in the face of a high clinical pretest probability estimate, additional tests are warranted.
2. What tests other than the V/P scan are available to diagnose PE?

Laboratory tests. Electrocardiogram, blood chemistry, arterial partial pressure of carbon dioxide (pCO₂) and arterial partial pressure of oxygen (pO₂) are not sufficiently sensitive or specific to diagnose PE. Similarly, the chest x-ray is not sensitive for PE, and when findings are present, they are often nonspecific. A blood marker of coagulation, D-dimer assay (DDA), measures fibrin degradation products in blood. The test is quite sensitive (95% in one study) for PE, but of low specificity (31%). Therefore a negative D-dimer result using the enzyme-linked immunosorbent assay (ELISA) method would weigh heavily against PE and could be used to help the clinician exclude the need for a V/P lung scan in cases in which a pretest probability is low. However, the American College of Chest Physicians consensus committee on PE recently concluded that until D-
Dimer testing is standardized and more widely validated in prospective outcome studies, widespread use of D-dimer measurement is not recommended.

**Imaging tests.** Pulmonary angiography is the gold standard for diagnosing PE. It provides an image that shows the emboli as filling defects in the contrast-enhanced blood within the pulmonary vasculature. Pulmonary perfusion imaging and pulmonary angiography agree closely in detecting pulmonary emboli, although both tests miss some emboli. Selective pulmonary angiography is more sensitive than perfusion lung imaging for detecting small, peripheral emboli and emboli that partially obstruct pulmonary vessels. But lack of good interobserver agreement in reading small emboli on the pulmonary angiogram somewhat diminishes that advantage. The pulmonary angiogram is expensive and has morbidity associated with injection contrast material and the highly invasive nature of the test.

Contrast-enhanced CT (spiral or electron-beam) can be performed as a rapid scan technique, which combined with intravenous contrast media, permits visualization of the central pulmonary artery and its proximal branches during a single breath-hold of 20 sec or less (electron-beam technique permits 1- to 2-sec imaging). Before spiral CT technology, prolonged scanning times resulted in respiratory and cardiac motion artifacts and poor definition of pulmonary vasculature. Sensitivity of 86% and specificity of 92% has been reported for central vessel PE and lower sensitivity, 63%, and specificity, 89%, for smaller vessel PE compared with pulmonary angiography. Assessments show that it may still be too early to tell if and how spiral CT will fit in the clinical workup of patients suspected of having PE. Recommendations have focused on patients with indeterminate V/P lung scan results or those with extensive chest x-ray infiltrates who are likely to have indeterminate V/P scans (Fig. 3). However, negative CT does not exclude PE because thromboemboli in subsegmental pulmonary arteries are not detected by CT.

Because of intravenous administration of iodinated contrast material and the associated mortality of 1 in 40,000 and morbidity reactions of 1 in 4,000, spiral CT and pulmonary angiography are less desirable alternatives than radionuclide V/P lung scan, which has almost no associated morbidity. Cost is variable, but usually lower for lung scans (see Chapter 29, Comparative Costs of Diagnostic Procedures). Cost of pulmonary angiography is far higher, as is risk to the patient. Some investigators have recommended that the contrast-enhanced CT study may prove to be a less costly alternative to pulmonary angiography and, occasionally, an alternative to radionuclide lung scan and pulmonary angiography (e.g., patients who cannot perform the ventilation test). Magnetic resonance imaging (MRI) is also at an investigational assessment stage in the workup of patients with suspected PE.

3. **What is the role of the pretest probability estimate of PE?**

The clinician can estimate the pretest probability for PE based on risk factors and clinical symptoms. Risk factors for PE and DVT include conditions that lead
to venous stasis and intimal injury, e.g., pelvic and lower extremity trauma and surgery, burns, pregnancy, postpartum state, estrogens, prolonged general anesthesia, prior DVT, mass or fibrosis impinging on venous drainage, congestive heart failure, prolonged immobility, obesity, cancer and advanced age. The most common clinical presenting signs and symptoms of patients with PE are dyspnea or tachypnea (96%), which are nonspecific signs and occur in a variety of other non–PE conditions. The classically quoted triad of PE—dyspnea, pleurisy and hemoptysis—occurs in only a small percentage of patients with PE. Hemoptysis is probably present only if pulmonary infarction has occurred, and fewer than 10% of PEs result in clinically evident pulmonary infarction.

As illustrated in Table 1, and demonstrated by the PIOPED multicenter study using pulmonary angiography as the gold standard, estimates of pretest likelihood of PE based on the clinician’s assessment are useful in maximizing the accuracy of the lung scan probability interpretation.

- Of patients with the combination of high clinical probability and high probability V/P scan, 95% had PE.
- Of patients with the combination of low clinical probability and high probability V/P scan, 83% had PE.
- Of patients with high clinical probability and low probability V/P scan, 43% had PE.

Further refinement of the low probability scan has led to the very low probability category which is associated with PE in <5–10% of cases with the identified scan findings.

4. How does the clinician proceed if the patient has an intermediate probability scan result?

Faced with an inconclusive V/P scan, the next step can be a contrast-enhanced spiral CT scan or a pulmonary angiogram. Algorithms for approaching the workup are suggested in Figure 3. Most physicians would probably agree that the upfront costs of additional diagnostic tests to diagnose PE when an inconclusive V/P scan result is obtained are outweighed by the benefits of basing anticoagulant therapy on a well-founded diagnosis. The incidence of nondiagnostic V/P scans range from about 10% to 50%, depending largely on the patient population sampled. At many hospitals only 10% of V/P scans are interpreted as intermediate probability for PE, whereas 90% are low or high probability. In the PIOPED population, 38% were intermediate probability. Patients with chronic obstructive pulmonary disease are more likely to have intermediate probability for PE, or nondiagnostic scans. But, the almost nonexistent morbidity and relatively low cost compared with pulmonary angiography make the V/P scan the most desirable first line test for PE, after the chest x-ray, which may identify pathology and is needed to correlate with the V/P scan.

Risk of inconclusive PE diagnosis and anticoagulation therapy risks. The risk of death from anticoagulation without a definite diagnosis is low (0.1%). But morbidity from anticoagulant therapies is higher (major bleeding in 5% and heparin-induced thrombocytopenia in 1%). Furthermore, the patient is committed to multiple months of anticoagulation, with considerable cost and inconvenience, as well as the morbidity risks described above. There is also a medicolegal risk to the physician in the event of morbidity from anticoagulation therapy despite an uncertain diagnosis. Therefore, some physicians order duplex ultrasound to diagnose DVT before starting anticoagulation therapy when the V/P scan is inconclusive or when it is delayed for 10–12 hr until morning. Anticoagulation therapy certainly is warranted for DVT, and 70% of patients with PE have positive ultrasound studies for DVT.

Most physicians experienced in diagnosis and therapy of patients with PE prefer to focus the diagnostic workup for PE on the chest, i.e., start with the chest x-ray and V/P lung scan. If an indeterminate probability for PE is found, lower extremity venous imaging may be performed to assist in assessing the likelihood of PE, in hopes of circumventing pulmonary angiography. If compression
Doppler ultrasound, for example, is positive, appropriate anticoagulation therapy is instituted, but if negative, pulmonary angiography or spiral CT still may be needed because the absence of a diagnosis of DVT does not exclude PE.

5. If the chest x-ray shows an infiltrate or effusion, can the V/P scan diagnose PE?

It is reasonable to perform the V/P scan in patients with an infiltrate or effusion; if the effusion is large, it is advisable to remove fluid before the scan, if possible, to assess the underlying lung. If the perfusion scan is relatively normal or low probability, despite focal lung opacification from fluid, the patient is spared more extensive testing. An infiltrate on chest x-ray can be a pulmonary infarct, pneumonia or a host of other pathologies. V/P scan with matched defect(s) leads to an intermediate probability for PE interpretation unless there are other mismatched defects with no accompanying density on chest x-ray. The triple-match, for which the infiltrate on x-ray and the V/P defect are equal in size, is interpreted as intermediate probability for lower lung zone lesions or very low probability for triple-matched defects in upper or middle lung fields. An effusion on chest x-ray usually will correspond to a matched V/P defect. Some data suggest that a small pleural effusion has a higher likelihood of PE than a large pleural effusion, although this interpretation is debated.

6. Should a patient being treated for PE have a follow-up scan? If so, when?

A corollary question, which sometimes arises, particularly if the patient has had a diagnosis of PE in the past, is can the V/P scan distinguish between acute and unresolved (chronic) PE? The V/P scan may not distinguish old from new PE without a prior study. Accurate interpretation of a new V/P scan in a patient with known prior PE requires comparison to a baseline V/P scan acquired after treatment of the prior PE.

The perfusion may normalize after anticoagulation therapy, but long-standing perfusion defects can remain, mimicking acute PE on a V/P scan. A baseline scan after anticoagulation is important in case the patient becomes symptomatic in the future and requires a new diagnostic V/P scan. Persistence of an unresolved defect, particularly if mismatched, will be difficult to sort out if a baseline scan is not available for comparison. The post-therapy lung scan can be obtained at the time of discharge from the hospital or at 3–6 wk as an outpatient.

7. What are the risks of PE, anticoagulation and a V/P scan during pregnancy?

During pregnancy, the incidence of PE and DVT are elevated. Mortality of untreated PE in pregnancy is 12.8%, whereas it is only 0.7% with therapy. Thus, the risk associated with untreated, undiagnosed PE in pregnancy is extremely high. However, the risk related to unnecessary anticoagulation therapy is also high. By contrast, the small risk to a fetus of radiation exposure (see below) from
diagnostic testing for PE in the mother is far outweighed by the risks of not diagnosing PE. A diagnosis of PE during pregnancy carries with it prolonged heparin therapy during pregnancy, potential need for prophylaxis if future pregnancies occur, concern about oral contraception and, later in life, concern about estrogen replacement therapy. Thus, a reasonably definitive diagnosis of PE must be pursued, starting with the V/P scan.

Radiation to the fetus from a radionuclide lung V/P study, in a nutshell, is a nonissue if the suspicion for PE exists. Although calculated fetal exposures from a diagnostic lung V/P scan are low, it is advisable to minimize the administered doses.

Many nuclear medicine physicians and radiologists obtain written informed consent from the pregnant patient before performing a lung scan or any necessary procedure involving radiation. In the report, it is advisable for the radiologist or nuclear physician to document the discussions with the patient about the risks and benefits of the test (see V/P Lung Scan Patient Information).

8. If a postpartum patient has a V/P scan, can she continue to breastfeed?

The postpartum patient who is nursing an infant is advised to discontinue nursing for 24 hr. Because the radiation is concentrated in the patient’s chest, holding the infant against the chest to nurse should be avoided for several hours. More importantly, a small amount of technetium from the $^{99m}$Tc-MAA complex may be excreted in the breast milk. However, because of the 6-hr physical half-life of technetium combined with biologic elimination, after 24 hr the amount of radioactivity excreted in the breast milk will be negligible. If there is any doubt, the best proof would be to count 1.0 ml of expressed milk, which should be close to background ($< 3 \times$ background) before resuming breastfeeding.

9. How much lung function will my patient lose if he/she has a partial lung resection?

Normal individuals have split lung functions of 52% right lung and 48% left lung. If global lung function as measured by pulmonary function indices is compromised substantially, the quantitative radionuclide lung V/P scan can assist in the critical surgical decision of how much lung can be removed while preserving remaining pulmonary function. The loss of lung function resulting from excision of a lobe or lung can thus be predicted in advance of the surgery.

10. Should a V/P scan be obtained to diagnose and quantitate right to left cardiac shunts?

Right to left shunts can be accurately quantitated by a perfusion lung scan that is modified to be a whole-body scan. When a right to left shunt is present, the first capillary bed to which intravenously injected shunted particles come is that of any organ system: brain, liver, kidneys, myocardium, etc., in proportion to
the percent of cardiac output blood delivered to that organ system. Thus, by imaging the whole body and measuring the lung counts compared with whole-body counts, the shunted blood (right to left) can be quantitated:

Percent right/left shunt = 
(whole-body counts − lung counts) ÷ whole-body counts.

Calculation of differential pulmonary blood flow, i.e., percentage of pulmonary artery blood going to each lung, is commonly used in the pediatric population in the assessment of severity of pulmonary artery stenosis, particularly before and after balloon dilation or stent placement.

11. Does my patient have DVT?

Venous imaging can be performed by several techniques. The traditional gold standard is contrast radiographic venography. This test is based on visualizing filling defects in well opacified venous channels to detect DVT. The major disadvantage of the radiographic contrast venogram is (a) pain, particularly if there is any extravasation of the contrast; (b) iatrogenic thrombosis induction (incidence about 10%); (c) problems of potential reaction to contrast material, which carries a mortality rate of 1:40,000; and (d) potential renal toxicity.

Noninvasive venous imaging using ultrasound (venous duplex scanning) has reasonably high accuracy with sensitivity and specificity of 90% or better and is the current preferred modality. Compression ultrasonography assesses compressibility of the femoral and popliteal veins, i.e., noncompressibility is diagnostic of DVT. The limitations of ultrasound include the following: (a) unreliable accuracy in calf DVT; (b) inability to differentiate acute from chronic recurrent DVT; and (c) highly operator-dependent nature.

Magnetic resonance venography has reported sensitivities of 90–100% and specificities of 93–100%; thus, it may be an excellent noninvasive approach for DVT. Because of cost considerations, it can follow the less expensive ultrasound if nondiagnostic or may be the first-line noninvasive test for some patients at particularly high risk for DVT. Another advantage of magnetic resonance venography is that it appears to be more sensitive than ultrasound in the pelvis and calf. However, it is not yet widely available and is more difficult to obtain than ultrasound on an emergency basis.

Impedance plethysmography is an indirect indicator of blood flow that is sensitive for proximal (above the knees) DVT in symptomatic patients. Impedence plethysmography is not sensitive in the calves, and it may miss nonocclusive proximal thrombi.

The newest imaging test for acute DVT diagnosis uses AcuTect (Fig. 2), a low molecular weight synthetic peptide labeled with technetium. This test is sensitive in the calf, giving an advantage over Doppler ultrasound for below-knee thrombosis. Statistical analyses from clinical trials indicate that AcuTect’s sensitivity to detect acute calf thrombi is 90.6% (specificity 83.9%), using contrast venography as the gold standard. Acute thrombosis imaging will play a role in
patients with indeterminate or nondiagnostic ultrasound and in patients with chronic venous disease who have symptoms of recurrent acute thrombosis. The diagnosis of DVT is sometimes used to aid in estimating a higher or lower likelihood of PE when the V/P scan is intermediate probability. Radionuclide venography (see section III, above), compared with contrast venography, has limitations including nonvisualization of the full extent of the thrombus, failure to detect nonocclusive and small thrombi and false-positive results when collateral vessels are visualized but no active thrombosis is noted by contrast venography.

For patients with suspected PE and DVT in whom ultrasound of the lower extremities is performed first and anticoagulation therapy is planned, the V/P scan should be performed as well. Besides documenting PE, the V/P scan can be used to document recurrence of PE by comparison with a subsequent V/P scan if the patient experiences symptoms of recurrence while on anticoagulant therapy. This indicates treatment failure, requiring alternative treatment measures.

**WORTH MENTIONING**

1. **Fibrinogen uptake test**
   This test measures active deposition of fibrinogen. It is no longer available, because the radiopharmaceutical, $^{125}$I-labeled fibrinogen, is not commercially produced in the United States.

2. **Impedance plethysmography**
   Impedance plethysmography is based on the electrical conduction of blood, such that the amount of blood in an extremity is inversely related to the impedance to the electrical conduction. An inflated cuff is used to impede venous drainage. When the cuff is released, there is a rapid fall in volume, but when obstruction is present, this fall is less pronounced and less rapid; in 86–94% of patients with DVT by renography proximal thrombi are detected by impedance plethysmography, but only 30% sensitivity is seen for thrombi in the calf.

**PATIENT INFORMATION**

1. **VENTILATION/PERFUSION LUNG SCAN**
   **A. Test/Procedure**
   The lung perfusion and ventilation scan gives your doctor pictures of the blood flow patterns and the ventilation (movement of air in your bronchial airway) in your lungs. These scans are used to detect blood clots blocking the blood flow in your lungs. They also tell your doctor which parts of your lungs are func-
tioning well and which parts are not. This test uses small amounts of radioactive materials to show blood flow in the lungs and air movement in the airway.

The ventilation and perfusion procedures take about 30–60 min. The perfusion lung scan is done by injecting a small amount of a radioactive material into a vein and then taking pictures. The ventilation lung scan is done by having you breathe in a small amount of a radioactive gas or aerosol and then taking pictures of your lungs.

**B. Preparation**

*Diet.* There is no special preparation for these studies. You can eat and drink fluids as usual.

*Medications.* There are no medication restrictions for this test. Depending on the findings and whether you need anticoagulation or other therapy, it may be advisable to repeat the lung scan at some time after therapy has been instituted or just before its completion to document the changes that have occurred in response to the therapy and to have this new baseline lung scan to compare with any scan needed in the future if this problem should recur.

**C. Radiation risks**

The amount of radiation used is small and similar to that given by other diagnostic x-ray tests. The radiation exposure to your whole body from this test is about 50% of the dose the average person living in the United States receives each year from cosmic rays and naturally occurring background radiation sources. The radiation dose is about 3% of the yearly dose considered safe for doctors and technologists who work with radiation. You can be around other people and use a bathroom normally without risk to others.

**D. Pregnancy**

If you are pregnant or think you might be pregnant, or if you are a nursing mother, please tell your physician so that this can be discussed with the nuclear medicine physician.

**II. ACUTECT VENOUS THROMBOSIS SCAN**

**A. Test/Procedure**

The AcuTect scan helps your doctor determine if you have had a recently formed blood clot in a vein, usually in your legs. After an intravenous injection in a vein unrelated to the suspected problem area, pictures will be obtained at 30 min and 4 hr after the injection.

**B. Preparation**

There is no special preparation and no medication restriction for this test.
C. Radiation risks
The amount of radiation used is small and similar to that given by other diagnostic x-ray tests. The radiation exposure to your whole body from this test is about 23% of the dose the average person living in the United States receives each year from cosmic rays and naturally occurring background radiation sources. The radiation dose is about 1.5% of the yearly dose considered safe for doctors and technologists who work with radiation. You can be around other people and use a bathroom normally without risk to others.

D. Pregnancy
If you are pregnant or think you might be pregnant, or if you are a nursing mother, please tell your physician so that this can be discussed with the nuclear medicine physician.

References