

# SPECT in Acute Pulmonary Embolism\*

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The purpose of this review was to evaluate the accuracy of SPECT in acute pulmonary embolism. Sparse data are available on the accuracy of SPECT based on an objective reference test. Several investigations were reported in which the reference standard for the diagnosis of pulmonary embolism was based in part on the results of SPECT or planar ventilation–perfusion (V/Q) imaging. The sensitivity of SPECT in all but one investigation was at least 90%, and specificity also was generally at least 90%. The sensitivity of SPECT in 4 of 5 investigations was higher than that of planar V/Q imaging. The specificity of SPECT was generally higher, equal, or only somewhat lower than that of planar V/Q imaging. Most investigators reported nondiagnostic SPECT V/Q scans in no more than 3% of cases. Methods of obtaining SPECT images, methods of obtaining planar V/Q images, and the criteria for interpretation varied. The general impression is that SPECT is more advantageous than planar V/Q imaging.

**Key Words:** pulmonary embolism; venous thromboembolic disease; pulmonary scintigraphy; SPECT; ventilation–perfusion lung scan; Technegas

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It is now nearly 2 decades since the Prospective Investigation of Pulmonary Embolism Diagnosis (PIOPED) (1) was published, and important advances have been made in imaging equipment, methods of interpretation, and radio-

pharmaceuticals. The ability to perform SPECT ventilation–perfusion (V/Q) imaging was still in its relatively early stages when the PIOPED investigation of V/Q scans was published (2). Dual and triple-head  $\gamma$ -cameras with ultra-high-resolution collimators have been developed (3–5). Improved diagnostic criteria have been proposed, including the revised PIOPED criteria (6,7), the Prospective Investigative Study of Acute Pulmonary Embolism Diagnosis (PISA-PED) criteria (8), very low probability interpretation (9–11), mismatched vascular defects (12), stratification according to prior cardiopulmonary disease (13), stratification of the number of mismatches required for diagnosis according to clinical assessment (14), and perfusion scintigraphy combined with chest radiography (15). A new radio-pharmaceutical for ventilatory studies is <sup>99m</sup>Tc-Technegas (Cyclomedica). It consists of ultrafine carbon particles that behave physiologically like a gas wash-in but lodge in the alveoli, thus retaining the advantages of aerosol imaging (16).

In principle, compared with traditional planar V/Q imaging, SPECT offers the advantage of tomographic sections (17,18). Many investigators have found SPECT V/Q imaging to be more advantageous than planar imaging (19–23). There are good reasons to believe that SPECT V/Q imaging could supersede planar scintigraphy (24). Among the advantages of SPECT is the avoidance of overlapping of small perfusion defects by normal tissue (24,25). In addition, having a higher contrast resolution than planar V/Q imaging, SPECT can detect abnormalities particularly at the subsegmental level and in the lung bases, where the segments are tightly packed (26). Experiments with phantoms have shown that perfusion defects in the mediobasal segment of the lower lobe could be unnoticed on planar imaging but not on SPECT (27).

CT angiography is the test of choice for suspected acute pulmonary embolism (PE) in many circumstances, but

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when CT angiography is not diagnostic or when it is contraindicated, other tests are needed. V/Q scintigraphy is an important alternative. Many suggest that SPECT may improve its performance. Despite the theoretic advantages of SPECT and the observations of several investigators, robust scientific evidence of the advantages of SPECT over planar imaging is sparse. Several have suggested that it is time for an investigation of the accuracy of SPECT V/Q imaging (16,24,25,28). Such an investigation should be rigorous and prospective, incorporating state-of-the-art techniques and revised criteria for interpretation (24). Until that can be accomplished, it would be useful to review the literature on the accuracy of SPECT V/Q imaging and how it compares with planar V/Q imaging. This review, therefore, was undertaken.

## MATERIALS AND METHODS

### Study Identification

We attempted to identify all published investigations in all languages that used SPECT to diagnose PE. A search of the literature in all languages was performed using PubMed, which includes MEDLINE, OLDMEDLINE, and Ovid. PubMed was searched through February 9, 2009. Separate searches were made using as search terms “single photon emission computed tomography” and “SPECT” matched with “pulmonary embolism.” Manual reference checks of recent reviews and all original investigations were performed to supplement the electronic searches. Data from the following were excluded: abstracts, case reports, letters, comments, reviews, animal studies, and in vitro studies.

### Statistical Methods

Sensitivity, specificity, and positive predictive value were reported as calculated by the investigators or were calculated from the investigators' data using standard methods (29).

## RESULTS

Published investigations of SPECT for the diagnosis of PE fell into several categories: accuracy studies of SPECT, comparisons of SPECT with planar V/Q imaging, outcome studies, and technical studies. The technical investigations included the use of reformatted planar V/Q scans from SPECT V/Q scans, the use of respiratory gating in SPECT image acquisition, the use of Technegas for SPECT ventilation scans, the use of fused SPECT perfusion imaging with CT angiography, automated detection of V/Q mismatches, and the use of a 3-dimensional format for interpretation.

### Accuracy Studies of SPECT

We are aware of only 2 investigations of SPECT perfusion or SPECT V/Q imaging that used either conventional or CT pulmonary angiography as an independent reference standard (Table 1) (4,30). Corbus et al. calculated an estimated positive predictive value, 18 of 29 (62%), as part of a larger outcome study (4).

Bajc et al. used CT angiography as a reference standard in part of a larger investigation (30). SPECT showed a sensitivity of 24 of 26 (92%) and specificity of 54 of 76 (71%) (Table 1). A diagnosis of PE by SPECT V/Q was

made if 2 or more mismatched segmental or subsegmental defects were shown, and PE was excluded by SPECT V/Q if no more than 1 mismatch was shown. Technegas was used for ventilation imaging. Among all patients evaluated by Bajc et al., the reference standard in many included SPECT. Sensitivity was 601 of 608 (99%), and specificity was 1,153 of 1,177 (98%).

Palla et al., in 1988, used conventional pulmonary angiography as the reference standard but obtained pulmonary angiograms only in patients who had abnormal planar perfusion findings (2). Sensitivity with SPECT was 56 of 62 (90%), but specificity was only 75 of 118 (64%) (Table 1). This was interpreted as indicating that some segmental defects detected by SPECT had no angiographic correlates. A mismatched defect in 1 or more segments was considered diagnostic of PE with SPECT perfusion imaging.  $^{133}\text{Xe}$  was used for planar ventilation imaging.

Several additional investigations of the accuracy of SPECT were reported in which the reference standard for the diagnosis of PE was based in part on the results of SPECT (19,23,31) or planar V/Q scans (20), angiograms were obtained on the basis of the SPECT results (32), or the reference standard may not have been described (Table 1) (22). Sensitivities of SPECT ranged from 80% to 100% (19,20,22,23,31). Specificities were usually in the range of 93%–100% (Table 1) (19,20,22,23,31). Sensitivity and specificity were not reported for some studies. The diagnostic criteria for PE by SPECT differed, and sensitivities and specificities were based on fewer than 50 patients in each study (Table 1). In 1 investigation, only positive predictive value was reported, 4 of 8 (50%) (32).

### Comparisons of SPECT with Planar V/Q Imaging

Comparison of SPECT perfusion imaging with planar V/Q imaging in general showed that SPECT gave more precise information about the site and extent of areas of deficient perfusion than did planar V/Q imaging (33). Some observed that SPECT showed mismatches (21), particularly subsegmental mismatches (34,35), more clearly than did planar V/Q imaging. Sensitivity was thought to be higher with SPECT than with conventional V/Q imaging (36), and review of 5 investigations supported this impression (2,19,20,22,23).

Palla et al. showed a higher sensitivity with SPECT than with planar V/Q imaging, 56 of 62 (90%) compared with 20 of 62 (32%), but lower specificity with SPECT, 75 of 118 (64%) compared with 103 of 118 (87%) (Table 2) (2). Ventilation images with  $^{133}\text{Xe}$  were obtained only in the view showing the largest perfusion defect.

Bajc et al., in 2004, reported results for 2 readers (19). Both reported a sensitivity with SPECT of 13 of 13 (100%). Planar V/Q imaging showed a lower sensitivity, 11 of 13 (85%) for reader A and 10 of 12 (83%) for reader B. Specificity with SPECT was 37 of 40 (93%) for reader A and 37 of 39 (95%) for reader B. Planar V/Q imaging showed a higher specificity, 40 of 40 (100%) for both readers. The

**TABLE 1. Accuracy Studies of SPECT**

Study	Reference standard	SPECT criteria	Ventilation agent	SPECT sensitivity	SPECT specificity	SPECT PPV	Prospective	Patient characteristic
Corbus (4)	Conventional angio	Revised PLOPED: high or inter = PE; low or normal = no PE	<sup>99m</sup> Tc-DTPA	Not done	Not done	18/29 (62%)	No	Consecutive suspected PE
Bajc (30)	CT angio	≥2 mismatches = PE; 1 mismatch = no PE	Technegas	24/26 (92%)	54/76 (71%)		No	Consecutive suspected PE
Bajc (30)	Consensus, SPECT, CT angio	≥2 mismatches = PE; 1 mismatch = no PE	Technegas	601/608 (99%)	1,153/1,177 (98%)		No	Consecutive suspected PE
Palla (2)	Conventional angio if planar V/Q perfusion defects	Defects in ≥ 1 segment	<sup>133</sup> Xe	56/62 (90%)	75/118 (64%)		Yes	All referred for suspected PE, not consecutive
Collart (20)	Consensus V/Q, sonography, CT angio, D-dimer	Wedge-shaped defect	Not done	12/15 (80%)	49/51 (96%)		Yes	Consecutive suspected PE in emergency department
Reinartz (22)	Not stated	≥1 mismatch	Technegas	Reader 1, 96% Reader 2, 93% Reader 3, 89%	Reader 1, 96% Reader 2, 100% Reader 3, 100%		No	Consecutive suspected PE
Reinartz (23)	Consensus, including SPECT and CT angio	≥1 mismatch	Technegas	36/37 (97%)	42/46 (91%)		No	Suspected PE
Bajc (19)	Consensus, including SPECT and CT angio	≥2 seg or subseg mismatches = PE; 0 mismatch = no PE	<sup>99m</sup> Tc-DTPA	Reader A, 13/13 (100%) Reader B, 13/13 (100%)	Reader A, 37/40 (93%) Reader B, 37/39 (95%)		Yes	51 suspected PE 2 treated PE
Hata (32)	CT angio if high or inter SPECT	Seg perfusion defect, 2 or 3 planes	Not done	Not done	Not done	4/8 (50%)	Yes	Screening after cancer surgery
Lemb (31)	SPECT better, new defects, or normalized = PE; SPECT unchanged = no PE	≥1 mismatch = PE; 0 mismatch = no PE	Technegas	44/46 (96%)	38/39 (97%)		No	All referred for suspected PE

PPV = positive predictive value; angio = angiography; inter = intermediate; seg = segmental; subseg = subsegmental.

**TABLE 2. Comparisons of SPECT with Planar V/Q Imaging**

Study	Reference standard	SPECT criteria	Planar V/Q criteria	Ventilation agent	Planar V/Q method	SPECT sensitivity	SPECT specificity	Planar V/Q sensitivity	Planar V/Q specificity	Prospective	Patient characteristic
Palla (2)	Conventional angiogram if planar V/Q perfusion defects	≥1 mismatch	McNeil criteria	<sup>133</sup> Xe	6-view conventional (ventilation only if no chest radiography abnormality matched perfusion)	56/62 (90%)	75/118 (64%)	20/62 (32%)	103/118 (87%)	Yes	All referred for suspected PE
Collart (20)	Consensus	Wedge-shaped defect	PISA-PED perfusion and revised PLOPED V/Q	Only planar ventilation was performed ( <sup>81m</sup> Kr)	6-view conventional	12/15 (80%)	49/51 (96%)	12/15 (80%)	40/51 (78%)	Yes	Consecutive suspected PE in emergency department
Reinartz (22)	Not stated	≥1 mismatch	≥1 mismatch	Technegas	Angular summed from SPECT	Reader 1, 96% Reader 2, 93% Reader 3, 89%	Reader 1, 96% Reader 2, 100% Reader 3, 100%	Reader 1, 79% Reader 2, 64% Reader 3, 61%	Reader 1, 97% Reader 2, 100% Reader 3, 100%	No	Consecutive suspected PE
Reinartz (23)	Consensus, including SPECT and CT angio	≥1 mismatch	≥1 mismatch	Technegas	Angular summed from SPECT	36/37 (97%)	42/46 (91%)	28/37 (76%)	39/46 (85%)	No	Suspected PE
Bajc (19)	Consensus, including SPECT and CT angio	≥2 seg or subseg mismatches = PE; 0 mismatch = no PE	≥2 seg or subseg mismatches = PE; subseg mismatches = PE; 0 mismatch = no PE	<sup>99m</sup> Tc-DTPA	4-view conventional	Reader A, 13/13 (100%)	Reader A, 37/40 (93%)	Reader A, 11/13 (85%)	Reader A, 40/40 (100%)	Yes	51 suspected PE
						Reader B, 13/13 (100%)	Reader B, 37/39 (95%)	Reader B, 10/12 (83%)	Reader B, 40/40 (100%)		2 treated PE

Angio = angiography; seg = segmental; subseg = subsegmental.

diagnosis of PE by scintigraphy was based on 2 or more segmental or subsegmental mismatched perfusion defects, and the exclusion of PE required no mismatched perfusion defects. Planar V/Q scans were obtained in only 4 views.  $^{99m}\text{Tc}$ -diethylenetriaminepentaacetate (DTPA) was used for the ventilation scans.

Collart et al. showed the same sensitivity with SPECT perfusion imaging and planar V/Q imaging, 12 of 15 (80%), but showed a higher specificity with SPECT perfusion imaging, 49 of 51 (96%), than with planar V/Q imaging, 40 of 51 (78%) (20). The diagnosis of PE on SPECT was based on visualization of a wedge-shaped defect in 3 planes (20). Planar perfusion scans were interpreted by the PISA-PED criteria ( $\geq 1$  wedge-shaped perfusion defect was indicative of PE), and planar V/Q scans were interpreted using the revised PLOPED criteria. The planar V/Q scans were obtained with 6 views, and  $^{81m}\text{Kr}$  was used for the planar ventilation scans.

Reinartz et al. performed 2 investigations in which SPECT V/Q images were compared with planar V/Q images (Table 2) (22,23). In the first investigation, in 2001 (22), the sensitivity of SPECT V/Q imaging (89%–96% with readers 1–3) was higher than that of reformatted planar V/Q imaging (61%–79% with readers 1–3). Specificities were similar (96%–100% with SPECT and 97%–100% with planar V/Q imaging). The second investigation, in 2004, by Reinartz et al. showed a sensitivity with SPECT of 36 of 37 (97%) which was higher than the sensitivity of reconstituted planar V/Q imaging using the angular summed method, 28 of 37 (76%) (23). Specificity was somewhat higher with SPECT V/Q imaging, 42 of 46 (91%) compared with 39 of 46 (85%). The diagnosis of PE was by consensus and may have been based on SPECT findings as well as other information, including CT angiography (23). A diagnosis of PE by angular summed planar V/Q imaging and SPECT V/Q imaging was made if any mismatched defect was shown, regardless of size (23). Both investigations used Technegas for ventilation scintigraphy.

### Nondiagnostic Studies

The main reason why scintigraphy fell into disuse after PLOPED is that 72% of planar V/Q scans were of low or intermediate probability, which is considered by many to be

nondiagnostic (1). If an intermediate-probability interpretation was considered nondiagnostic, then 41 of 1,024 (4%) SPECT V/Q images evaluated by Corbus et al. would have been nondiagnostic (4). An additional 840 of 1,024 (82%) had low-probability interpretations, which also would have been considered nondiagnostic in PLOPED (1). Neither of these categories was considered nondiagnostic in the interpretation of SPECT by Corbus et al. (4). Nondiagnostic SPECT V/Q scans were shown by Leblanc et al. in 18 of 584 cases (3%), Bajc et al. in 19 of 2,328 (1%), and Lemb et al. in 5 of 991 (0.5%) (16,30,31). Nondiagnostic SPECT perfusion scans were found in 2 of 114 cases (2%) (1 low probability and 1 intermediate probability) by Collart et al. (20). In comparison, planar V/Q scans were of low probability in 32 of 66 cases (48%) and of intermediate probability in 9 of 66 cases (14%) (20). Other investigators did not report nondiagnostic studies with SPECT V/Q scans (2,19,22,23,32) or planar V/Q scans (2,19,22,23).

### Outcome Studies

An outcome study by Corbus et al. with SPECT V/Q scans showed 3.3% false-negative results among 813 patients followed for 3 mo (Table 3) (4). A low-probability interpretation according to the revised PLOPED criteria, as well as a normal SPECT V/Q finding, excluded PE. Ventilation imaging was with  $^{99m}\text{Tc}$ -DTPA.

Leblanc et al., using SPECT V/Q imaging, showed false-negative results in 6 of 405 patients (1.5%) followed for 3 mo or longer (Table 3) (16). Pulmonary embolism was considered absent by SPECT V/Q imaging if there were no mismatched perfusion defects (16). Technegas was used for ventilation scintigraphy.

Two publications (37,38) have shown that planar V/Q scans exclude PE with no less of a negative predictive value than SPECT scans, although Anderson et al. (37) used findings in addition to V/Q scans to exclude PE. Pulmonary embolism was excluded by normal planar V/Q findings or nondiagnostic V/Q findings with negative leg ultrasonography results plus either an “unlikely” Wells’ score of less than 4.5 or a negative D-dimer result (37). Anderson et al. showed PE on 3-mo follow-up in only 4 of 611 patients (0.7%). In an additional 0.3%, DVT had developed by the 3-mo follow-up (37).

**TABLE 3.** Outcome Studies

Study	Reference standard	SPECT criteria	V agent	NPV	Prospective	Patient characteristics
Corbus (4)	Outcome	Revised PLOPED: high or inter = PE; low or normal = no PE	$^{99m}\text{Tc}$ -DTPA	786/813 (97%)	Some yes	Consecutive suspected PE
Leblanc (16)	Outcome	$\geq 1$ mismatch = PE; 0 mismatch = no PE	Technegas	399/405 (99%)	Yes	Consecutive suspected PE

NPV = negative predictive value.

In a Montefiore study, PE was excluded in patients in the emergency department if they had a negative or very low probability V/Q result and normal or near-normal chest radiography findings (38). In 1.1% of such patients, PE or DVT was shown at the 3-mo follow-up.

### Technical Studies

**Reformatted Planar V/Q Scans from SPECT V/Q Scans.** Two methods for producing planarlike V/Q scans from SPECT V/Q scans have been described: the angular summed method (22,23) and reprojected scans (39). Comparisons of reprojected images with standard planar V/Q scans showed similar detail and distribution of radiopharmaceuticals (39). It was believed that reprojected images could replace true planar images with no loss of diagnostic sensitivity (39). Subsequent comparisons showed that reprojected reconstructions resulted in more matched defects but no differences in interpretation from true planar V/Q scans (40). By contrast, angular summed reformatting of V/Q scans caused a perceived decreased likelihood of PE (40). This was thought to be related to blurring of small defects that may have occurred when images acquired over an angular range were summed. The general consensus is that reformatted planar images are not a bona fide substitute for true planar images. A comparison of reformatted planar images with conventional planar images using an objective reference test has not yet been performed.

**Respiratory Gating.** Respiration-gated perfusion SPECT was applied to reduce the effects of respiratory lung motion (41). End-inspiratory and end-expiratory images were derived. Although the total lung radioactivity of the gated images was reduced to approximately 13% of that of the ungated images, the gated images showed uniform perfusion in the unaffected lung and showed 21.9% additional perfusion defects. The technique appeared to enhance the clarity of perfusion defects (41).

**Technegas for Ventilation Scans.** In the opinion of some, Technegas is a superior agent essential for high-quality SPECT V/Q imaging (3). The use of Technegas as a diagnostic radioaerosol was first reported in 1986 (42). Technegas is composed of hexagonal platelets of metallic technetium, each closely encapsulated with a thin layer of graphite carbon (43). The mean diameter of the particles is between 30 and 60 nm (43). Technegas is considered to behave truly like a gas because of the ultrafine dispersion of the particles (44). In addition, the distribution in vivo of the Technegas particles remains fixed for the duration of the study—a prerequisite for artifact-free reconstructed images. Although the clearance of other radiotracers such as  $^{99m}\text{Tc}$ -DTPA aerosols from the airways has a slight advantage in radiation dose, the change in distribution violates a fundamental requirement for image reconstruction in SPECT.

**Radiation Doses.** One potential indication for SPECT VQ imaging rather than CT angiography in suspected PE is patients for whom radiation dose is a particular concern. Accordingly, it is important to consider radiation dose when

evaluating SPECT as a substitute for, or complement to, CT angiography. Although SPECT as an acquisition technology does not inherently alter radiation dosimetry, the activity and biologic behavior of radiopharmaceuticals used for SPECT should be considered.

Perfusion scintigraphy, using a mean activity of 206 MBq of  $^{99m}\text{Tc}$ -labeled macroaggregated albumin, would result in an effective dose of 3.4 mSv (23). This amount of activity is about 20% greater than the 148 MBq typically used for planar perfusion studies, and radiation dose is proportionally greater. The application of 500 MBq of activity within the lung (5,45) with Technegas for the ventilation images leads to an effective dose of up to 1.5 mSv (23), higher than the effective dose for xenon or  $^{99m}\text{Tc}$ -DTPA (23,46).

Total effective dose with SPECT V/Q scintigraphy using  $^{99m}\text{Tc}$ -technegas would be 4.9 mSv. However, other investigators, using even somewhat more  $^{99m}\text{Tc}$ -macroaggregated albumin (220 MBq) and Technegas for the ventilation scan, calculated an effective dose for the combined SPECT V/Q scan of 2.5 mSv or less (47). In comparison, the effective dose in a phantom with 64-slice CT pulmonary angiography was 19.9 mSv (48).

**Fused SPECT Perfusion Imaging with CT Angiography.** An automated procedure (Hermes Multimodality Fusion program; Hermes Medical Solutions) that uses a mutual information algorithm was applied to register ventilation and perfusion images to each other (5). Through an iterative approach, which minimized the global sum of the SD of intensities between the 2 images' corresponding voxels, this technique adjusted the SPECT data using rigid transformation to match CT pulmonary angiographic data (5). The CT pulmonary angiographic data were transferred by Digital Imaging and Communications in Medicine to a Hermes workstation. The automated procedure registered the ventilation and perfusion images individually to the CT angiographic images (5). Among 30 patients evaluated retrospectively, fused images were shown to be particularly useful in patients with nondiagnostic findings on CT angiography or SPECT V/Q imaging. Three of 11 SPECT V/Q scans initially reported as being of intermediate probability could be reinterpreted as low probability because of colocalization of defects with parenchymal or pleural pathology (5).

Suga et al. (49) showed variable relationships between thrombi and regional perfusion in the lungs distal to the PE. Fusion images provided information about the effects of PE on peripheral perfusion (49). In 4 of 34 patients (12%), perfusion defects were absent from lung territories with PE (1 lobar branch and 3 segmental branches) (50). Conversely, in 4 other patients who did not have PE in vessels in the lung territory, perfusion defects were observed in the territory despite the absence of PE from the branches (50). There was, therefore, an unexpected dissociation between the localized PE and lung perfusion defects in some patients (50), although correlation with fusion images

previously appeared useful for clarifying the cause of perfusion defects (51).

*Automated Detection of V/Q Mismatches.* Objective interpretation of SPECT V/Q scans has been accomplished with various algorithms. Reinartz et al. (45) obtained an automated detection of mismatched perfusion defects in 2 steps. In step 1, the perfusion scintigram was subtracted from the normalized ventilation scintigram, so that the resulting image contained only mismatched defects. These were defined as regions of regular ventilation but severely reduced or absence of perfusion. In step 2, the subtracted image was fused with the perfusion scan to improve topographic orientation. The algorithm produced images that were easy to read. Sensitivity with automated detection increased from 20 of 22 (91%) to 21 of 22 (95%), but specificity with automated detection was lower, 26 of 31 (84%) compared with 30 of 31 (97%) based on visual interpretation (45). It was thought that artifacts were introduced by the automated approach, thereby decreasing diagnostic accuracy. Ventilation scans were obtained with Technegas.

Palmer et al. developed an iterative reconstruction using ordered-subset expectation maximization with 8 subsets and 2 iterations (21,52). As the images are processed, the ventilation background is subtracted from the perfusion tomograms and a normalized V/Q image set calculated (52). The main consideration was to permit a display in a fixed linear scale allowing separation of normal regions from those with a mismatch (52). Computerized normalized V/Q images facilitate diagnosis and quantification of PE extension (52).

Harris et al. used computer-assisted analysis based on the hypothesis that regions of PE should have a V/Q relationship different from that of the surrounding lung (53). Each distinct functional population should have a lognormal V/Q distribution. By iteratively fitting multiple lognormal curves, the investigators obtained a parameter termed the weighted median V/Q value. This parameter describes deviation of the V/Q distribution from normal by handling each functional subpopulation individually (53). With objective analysis among 50 patients, negative predictive value was 96% and positive predictive value was 83%. The diagnosis or exclusion of PE was by consensus based on clinical findings, CT angiography, CT venography, and 6-view planar V/Q scans. Ventilation scans were obtained with Technegas.

*3-Dimensional Format for Interpretation.* Among 20 patients who by final unspecified clinical diagnosis did not have PE, a higher proportion of images was normal by the 3-dimensional format, 14 (70%), than by coronal display, 11 (55%), or by planar V/Q imaging, 8 (40%) (54).

## DISCUSSION

In most hospitals in the United States, CT angiography has become the diagnostic imaging test of choice for

patients with suspected acute PE. Certainly, when CT angiography is nondiagnostic or contraindicated, other studies, particularly V/Q lung scans, may be useful. Moreover, there has been renewed interest in the use of V/Q imaging as the initial imaging test for acute PE. This has resulted from improved instrumentation and improved interpretation of lung scans, as well as concerns about high radiation exposure from CT angiography, particularly to the female breast. Outcome studies have supported the use of V/Q lung scans as the first imaging test in patients with suspected acute PE, since false-negative rates are close to 1%, which is similar to the rate for CT angiography. Several reports from outside the United States strongly suggest that SPECT further improves the performance of pulmonary scintigraphy. Pulmonary scintigraphy, especially SPECT, might be particularly useful for follow-up examinations of patients, a situation in which radiation from multiple CT angiograms might well be avoided.

Sparse data are available on the accuracy of SPECT based on an objective reference test. Important methodologic problems affect the validity of many investigations. In particular, several investigations of the accuracy of SPECT were reported in which the reference standard for the diagnosis of PE was based in part on the results of SPECT. The general impression, however, is that SPECT is more advantageous than planar V/Q imaging. A difficulty in assessing the literature on SPECT is variability in methods of obtaining the SPECT images and the planar V/Q images with which they were compared and variability in criteria for interpretation. Older studies were performed with single-head scintillation cameras, but presently dual- and triple-head cameras are used. Total acquisition times for SPECT V/Q imaging has decreased from 27 min for a single-head camera to 19 or 20 min for dual-head cameras and 13 or 14 min for triple-head cameras (4,5,21), although some reported a 32-min total acquisition time for dual-head cameras and 20 min for triple-head cameras (22). <sup>99m</sup>Tc-DTPA aerosol for ventilation scans has been replaced by Technegas in countries where it is approved (Europe, Canada, and Australia). Improved software for image analysis is now available.

Fused SPECT perfusion imaging with CT angiography, automated detection of V/Q mismatches, and a 3-dimensional format for interpretation may augment the ability to diagnose or exclude PE with SPECT.

## CONCLUSION

CT angiography is the test of choice in many circumstances and in most institutions currently, but when it is not diagnostic (e.g., when the CT angiography result and clinical assessment are disparate) or when it is contraindicated (e.g., when there are concerns about exposure to iodinated contrast material or ionizing radiation), other tests are needed. Historically, V/Q imaging fulfilled this role as a primary or secondary imaging modality. Although

V/Q imaging fell out of favor several years ago, more recently it has experienced a resurgence of interest and use because of concerns about the exposure of the population at large and specific high-risk subgroups to the high radiation doses generated by CT, and because of recent work that has shown substantial improvement in the accuracy and a reduced nondiagnostic rate of V/Q imaging. The working hypothesis of many clinicians and of this review is that SPECT and other modern techniques may further improve the performance of V/Q imaging. In view of the promising results but limited data and consequent uncertainty about the accuracy of SPECT scintigraphy for PE, it is time for a large prospective evaluation.

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