

# Impact of single photon emission tomography combined with computed tomography (SPECT/CT) in pulmonary examinations — short review with two case reports

Marina Garcheva  
 Medical University-Sofia, Department of Nuclear Medicine

[Received 9 I 2014; Accepted 7 VII 2014]

## Abstract

The hybrid ventilation/perfusion (V/P) examination SPECT/CT improves the diagnostic accuracy of lung scintigraphy for pulmonary embolism (PE). It reduces the false-positive results and increases the specificity of examinations. The co-registered V/P and CT scans provide more precise functional information, as well as additional data about pulmonary parenchyma, pleural and mediastinal structures. The CT acquisition is typically low-dose and can be implemented with little additional acquisition time and radiation exposure. It is convenient as a primary examination for patients with contrast-related contraindications, young patients and premenopausal women, because of the low whole body and breast exposure. It can be also used for the follow-up of the patients' recovery, for functional quantification, radiotherapy planning and for the prediction of radiation-associated complications. Two clinical cases from our practice present the impact of SPECT/CT application in the primary diagnosis and in the follow-up of patients with pulmonary embolism.

**KEY words:** V/P lung scintigraphy, SPECT/CT, pulmonary embolism (PE)

Nuclear Med Rev 2014; 17, 2: 101–107

## Introduction

The application of the new hybrid method SPECT/CT currently increases, by adopting more and more topics. The pulmonary ventilation (V) and perfusion (P) examinations were introduced almost 50 years ago. Recently they joined the SPECT/CT examinations.

One of the frequent indications of V/P scanning is the diagnostics of pulmonary embolism (PE). It is clinically challenging and needs an imaging confirmation. V/P scanning was the first-line imaging test study until the advent of helical CT and CT pulmonary angiography (CTPA). The traditional problem with V/P scanning is the high incidence of indeterminate results. CTPA

became the method of choice, visualizing directly the thrombi in the pulmonary tree (Figure 1). It is available in emergency situations, and convenient for differentiation of PE, myocardial infar-



**Figure 1.** Contrast enhanced CT: CTPA. Visualization of the thrombi in the pulmonary tree

Correspondence to: Marina Garcheva, MD, Prof. Assoc.  
 Medical University-Sofia, Department of Nuclear Medicine  
 2, Zdrave str. 1431, Sofia, Bulgaria  
 E-mail: marina.garcheva@gmail.com

tion, and aortic dissection. It also provides additional information about lung parenchyma and eventual pleural, pericardial and mediastinal pathology. The limitations of the method concern up to 23–31% of patients that may need imaging test [1, 2]. They are related to radiation exposure (high breast exposure unacceptable in premenopausal women: 20–50 mGy v/s 1.3 for V/P scan [3]), or to contrast contraindications (renal failure, severe contrast allergy, diabetics on metformin). V/P SPECT /CT can replace CTPA in these patients. It is related to lower exposure (effective dose 3.5 v/s 5–11 mSv). Its functional character facilitates the evaluation of the defects' resolution, and the detection of eventual new defects, which promote it as a test of choice for the follow-up.

V/P examination has been recently re-evaluated especially with regard to its specificity (Sp) and inconclusive rate [4, 5]. Several improvements in registration and interpretation have been introduced:

1. Change in the interpretation criteria — revised criteria (PIOPED II) with increase of Positive Predictive Value to 80% for PE of 0.5 segmental equivalent mismatched defect for patients without cardiopulmonary disease and 2 segment equivalent mismatched defects for those with history of cardiopulmonary disease [5] (lung segments on Figure 2).
2. Use of <sup>99m</sup>Tc labeled Technegaz as V-imaging agent permitting a multiple view registration and “frozen images” after one inhalation, without central deposition.
3. SPECT — registration, which provides the opportunity to visualize all lung segments, even medio-basal without superimposition, and to detect 53% more defects [6, 7]. The detection rate of defects on the subsegmental level actually increases by 83% and at the segmental level — by 18% [4] (Figure 3).

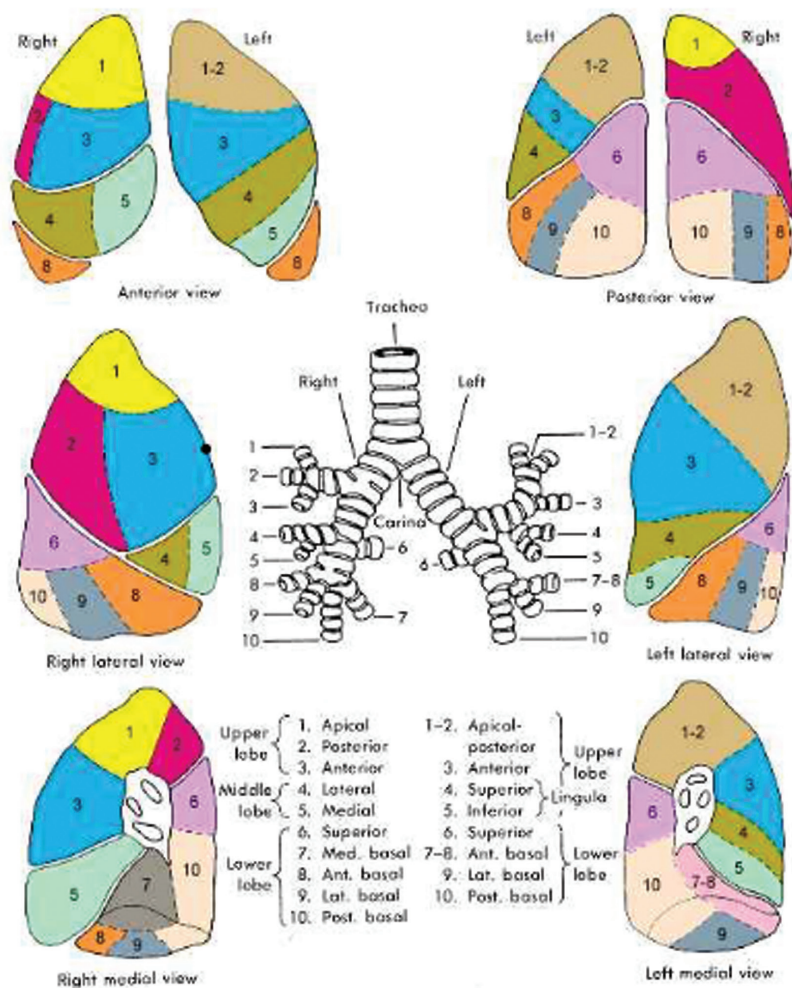
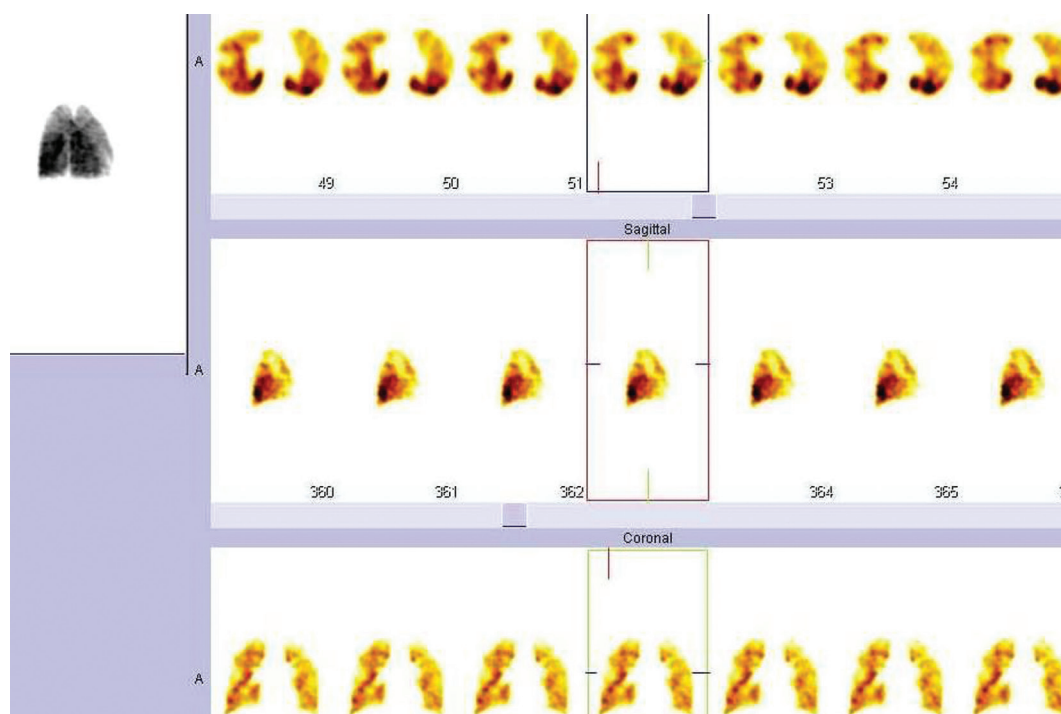


Figure 2. Pulmonary segments



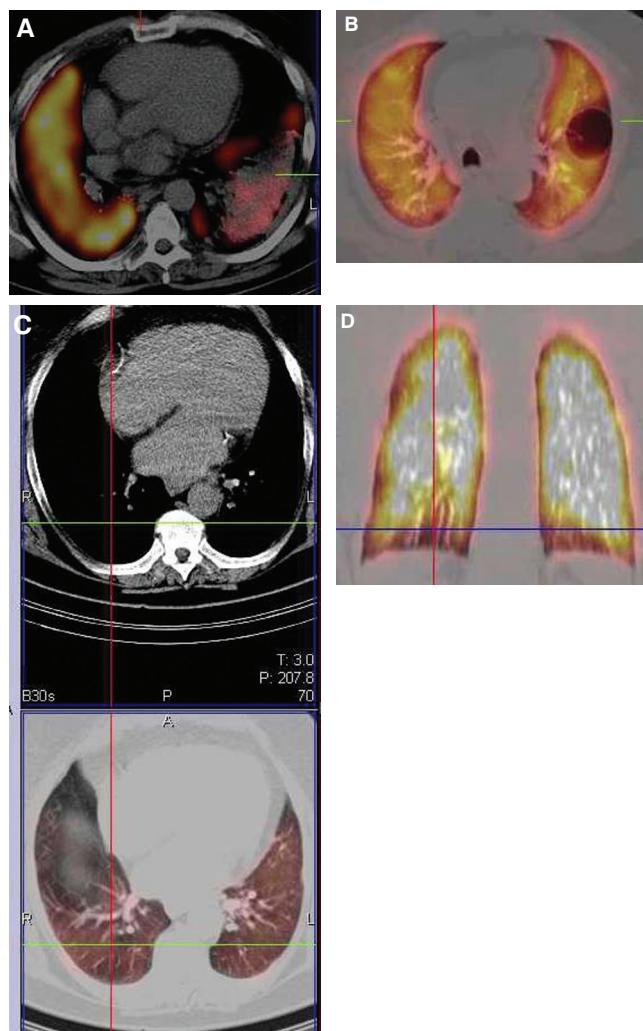
**Figure 3.** Subsegmental defects on SPECT images in 3 planes (axial, coronal and sagittal) and 3-D rotating

**Table 1.** Comparison of CTPA and V/P scan (S, Sp PPV, NPV)

Time period	CTPA	V/P	
1990	S 95%	S 84.9%	Planar registration
	Inconclusive rate 0%	Sp 80.1%	PIOPED criteria [8]
		Inconclusive rate 0%	
		S 80.4%	
2004		Sp 96.6%	Introducing PISAPED criteria (perfusion only scintigraphy) [9–11]
	S 86%	Inconclusive rate 0%	
	Sp 98%	S 97%	Introducing SPECT [4]
		Sp 91%	
2008	S 68%	S 97%	Introducing SPECT/CT to V/P [12]
	Sp 100%	Sp 100%	
	PPV 100%	PPV 100%	
	NPV 83%	NPV 98%	
		S 93%	Introducing SPECT/CT to P [12]
2009		Sp 51%	
		PPV 57%	
		NPV 91%	
		S 83%	Agreement with CTPA 95% [13]
		Sp 98%	
	PPV 95%		
	NPV 94%		

- Hybrid examination with low-dose CT component (LDCT).
- The investigators have recently determined better sensitivity (S), specificity (Sp) and positive (PPV) and negative predictive values (NPV) and lower rate of inconclusive results for V/P SPECT and V/P SPECT/CT (Table 1).

The recent data prove comparable sensitivity and specificity of CTPA and V/P SPECT/CT. The positive effect is due to the tomographic registration, as well as to the fusion with LDCT. LDCT attributes some perfusion defects to cardiomegaly, prominent hilum, effusions, atelectasis, bullae, or fissures in



**Figure 4.** Fused images: **A.** plate-like atelectasis; **B.** bullae; **C.** cardiomegaly; **D.** bronchiectases

one-moment tomographic registration (Figure 4, 5). Alternative diagnoses, such as granulomatous diseases, tumors, or metastases (Figure 6), pneumonic consolidations lymphadenopathy, are frequent. That is why the CT component should be meticulously included in the reporting. The fusion of SPECT and CT

images can be problematic, with breathing artifacts (Figure 7). The mid-inspiration CT registration is recommended, or an automated breath-hold perfusion SPECT/CT registration [14].

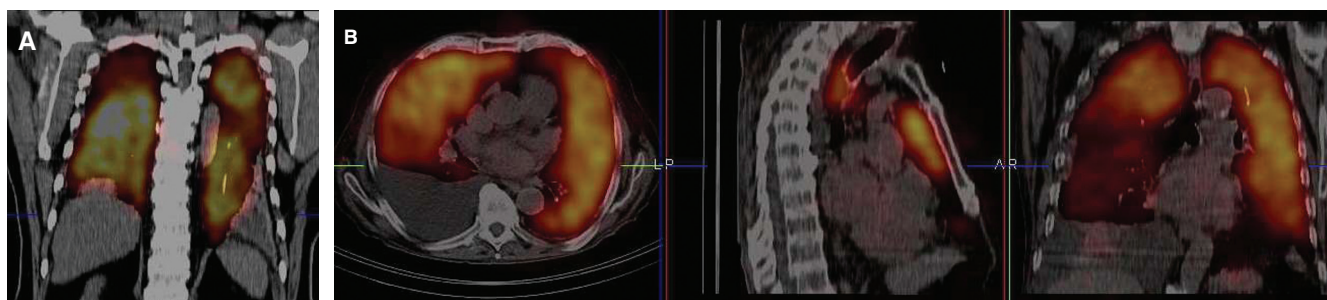
The CT-component provides some evidences confirming PE: distal to the embolus focus of oligemia leading to vessel collapse (vascular rarefaction), infarction related consolidation of lung parenchyma (Hampton hump), or dilatation of pulmonary trunk related to the pulmonary hypertension (Figure 8A, B, Figure 12A).

The reporting should include the pretest probability of PE [European guidelines, 15]. The patients with cardio-pulmonary co-morbidity could be problematic for interpretation [16]. All patients with chronic obstructive pulmonary disease (COPD) have low CT lung attenuation areas (emphysema, or air trapping, bulla or bronchial enlargement). All patients with interstitial lung disease have high CT attenuation areas representative of interstitial thickening. In COPD the areas with better preserved perfusion correspond to the areas with preserved parenchyma. These patients could have: matched or reverse mismatched defects (alveolar destruction, inflation and hypoxic vasoconstriction, plugs, inflammation [17], or segmental mismatch (vascular remodeling or obliteration, or superimposed PE). This variety of defects makes the evaluation much more difficult (Figure 9). In congestive heart failure (CHF), an inverse deposition of the perfusion radiopharmaceutical, redistributed towards upper lung region, is present. The perfusion is more affected than the ventilation, but without segmental character, which permits the detection of eventual superimposed PE [18] (Figure 10).

Cases 1 and 2 demonstrate the diagnostic value and the impact of the appropriate use of SPECT/CT in lung examinations.

### Case 1 (Figure 11A-C)

Thirty-year-old woman, after 2 hours of travel-flight, with acute pleuritic pain in the left thoracic wall, shortness of breath. Planar examination identified no definite defect. On SPECT/CT images — small zone of hypoperfusion and consolidation in the costo-diaphragmatic angle, pointing to the diagnosis of pulmonary embolism and pulmonary infarction. The patient was examined and found positive for Factor V Leiden gene abnormality, predisposing an increased risk of pulmonary venous thrombosis.



**Figure 5.** Fused images: **A.** small pleural effusion, related to PE; **B.** large effusion, without PE

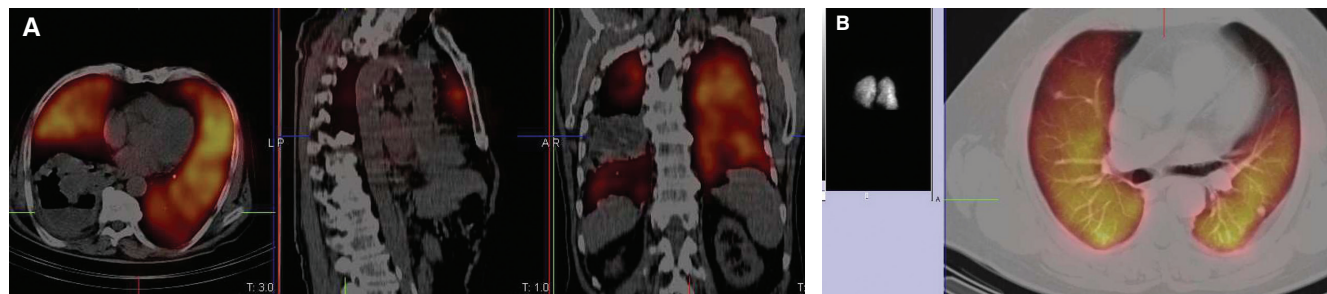


Figure 6. Unexpected pathology: A. tumors; B. metastases

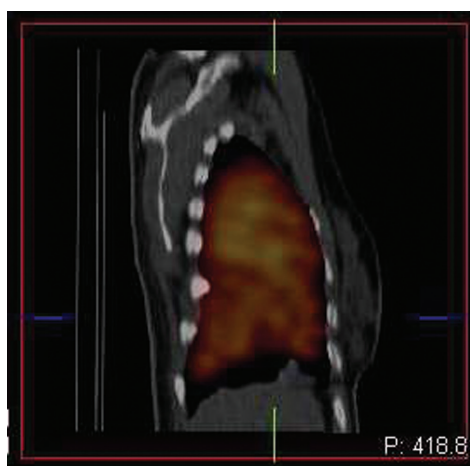


Figure 7. Breathing artifact

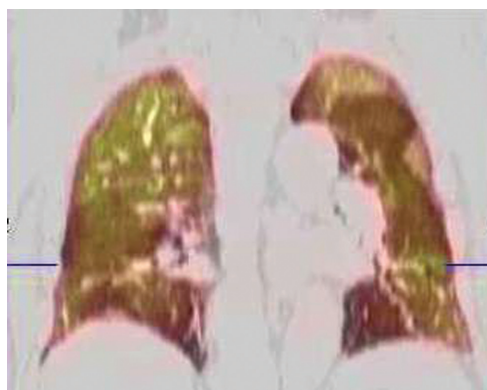


Figure 9. COPD — preserved perfusion in areas with preserved parenchyma

### Case 2 (Figure 12A-C)

Twenty-eight-year-old woman, on contraceptives, with massive PE in the right lung, detected by CTPA. The follow-up was done by SPECT/CT, which after 2 months demonstrated partial resolution of perfusion abnormalities and of the pulmonary infarction in comparison with basal examination (Figure 12B by courtesy of D. Zlatareva from the Radiology Department of the University Hospital — “Alexandrovska”).

### Discussion

Different opinions exist about the perfusion only SPECT/CT. Some authors declared that it cannot replace the ventilation scan [19].

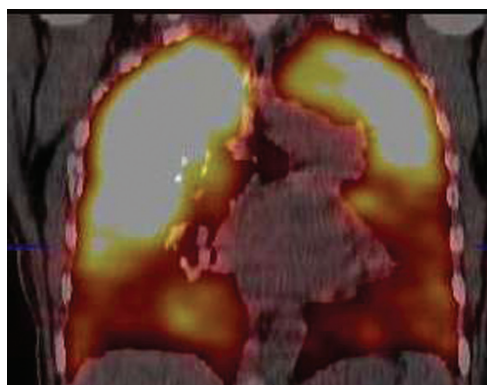


Figure 10. CHF — inverse distribution and superimposed PE

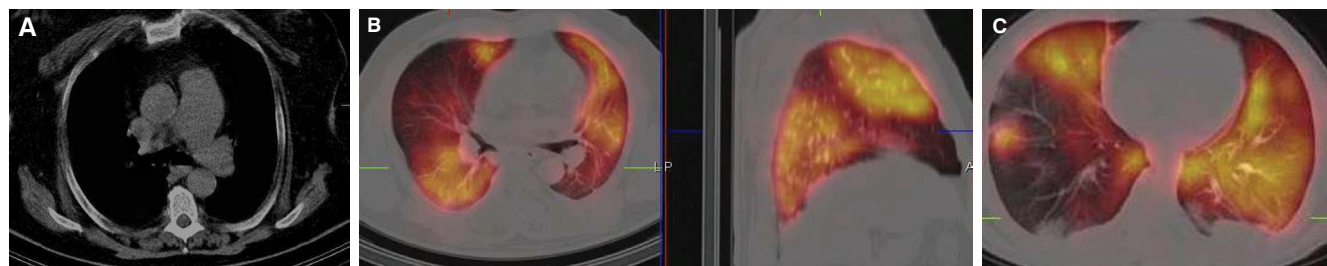
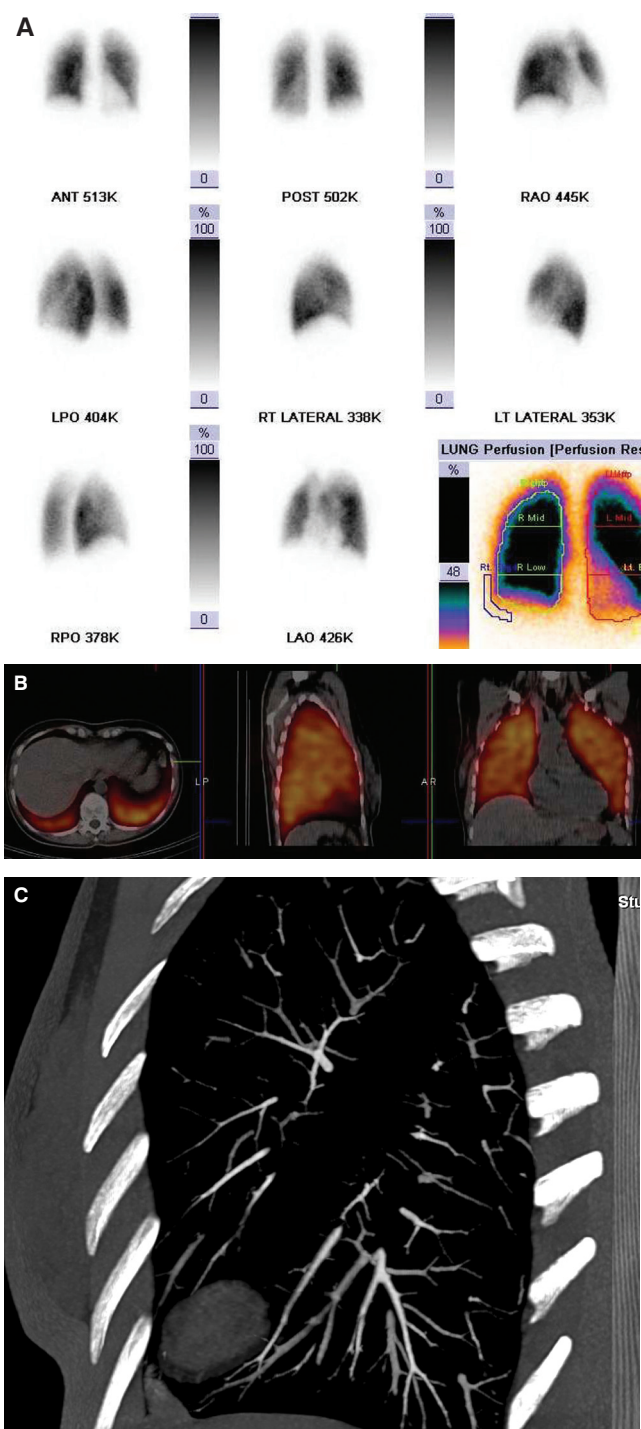
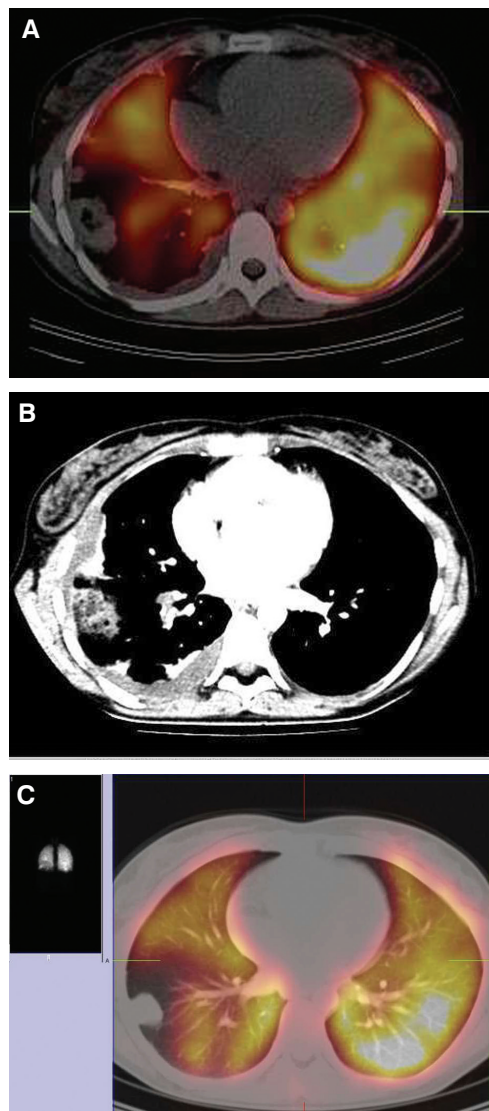


Figure 8. CT signs for PE: A. pulmonary trunk dilatation due to pulmonary hypertension; B. Westermark sign (vascular rarefaction); C. hemorrhages with fast resolution



**Figure 11.** Case 1. SPECT/CT for the diagnosis of PE with pulmonary infarction: **A.** planar examination; **B.** SPECT/CT; **C.** CTPA

The reported S is good — 93%, but the Sp is low — 51% with 18% inconclusive rate [12]. Difficulties can be expected in the interpretation in patients with COPD, because of the low-attenuation areas, which can mimic vascular rarefaction. Nevertheless, the perfusion only scintigraphy is also in use with recently reported S 82%, and specificity — 96% [10, 11]. The perfusion scan is attributed to 4 categories: normal, nearly normal (with defects explained by



**Figure 12.** Case 2. SPECT/CT for the follow-up of young women with PE: **A.** basal SPECT/CT; **B.** CTPA; **C.** SPECT/CT follow-up

CT-visualized structures), abnormal (with multiple wedge-shaped defects), abnormal (not suggestive PE). Unlike PLOPED (with probabilistic classification), in PISA-PED the results of perfusion lung scintigraphy alone categorize patients as positive, or negative. The criteria for PE are wedge shaped defects with segmental or sub-segmental distribution and usually wedge-shaped areas of overperfusion.

SPECT/CT can be very useful in functional quantification because of its regional accuracy, without superimposition of segments [20]. Semiquantitative evaluation of perfusion was proposed by dividing the lung into 18 segments, with 1-point for subsegmental loss, or segmental reduction, and 2 points for segmental loss [21]. A more precise, absolute quantification model, exists, taking into consideration the net activity applied, the attenuation and scatter correction [22].

Another possible application of SPECT/CT is the prediction of radiation-associated pulmonary damage. The acute damage — radiation pneumonitis can be found in 10% of patients (in relation

to the exposure, its fractionation, and lung volume with accumulated dose > 20 Gy). Pulmonary fibrosis, as a sign of late toxicity appears 3–4 months later, up to 18 months after radiotherapy. The perfusion, measured at the 18th month is indicative for the long-term pulmonary function. The V/P scan is important to predict the effect of radiation on the pulmonary function in preexisting perfusion deficiency [23, 24]. A semi-quantitative SPECT/CT evaluation was proposed [21] with lung perfusion score > 5 predictive for radiation related pulmonary complications. Another possible application is the defining the highly perfused lung regions for radiotherapy planning aimed at sparing them [25].

## Conclusion

There are considerable benefits of SPECT/CT application in lung diseases evaluation (even when LDCT is fused only with perfusion scan): improved sensitivity, specificity, morphological details, detection of other pathology. No absolute contraindications exist; the examination is well tolerated by patients. Since a lot of patients who undergo CTPA do not have PE, lung SPECT/CT as an alternate to CTPA imaging modality with lower exposure and without side-effects should be promoted.

## References

- Weinmann P, Moretti J-L, Brauner M. Usefulness of tomographic versus planar lung scintigraphy in suspected pulmonary embolism in a daily practice. *The Open Medical Imaging Journal* 2008; 49: 1874–3471.
- International commission on radiological protection. ICRP publication 87: managing patient dose in computed tomography. *Ann ICRP* 2000; 30: 7–45.
- Stein PD, Fowler SE, Goodman LR et al. Multidetector computed tomography for acute pulmonary embolism. *N Engl J Med* 2006; 354: 2317–2327.
- Reinartz P, Wildberger JE, Schaefer W et al. Tomographic imaging in the diagnosis of pulmonary embolism: a comparison between V/Q lung scintigraphy in SPECT technique and multislice spiral CT. *J Nucl Med* 2004; 45: 1501–1508.
- Gottschalk A. New criteria for ventilation-perfusion lung scan interpretation: a basis for optimal interaction with helical CT angiography. *Radiographics* 2000; 20: 1206–1210.
- Bajc M, Jonson B. Ventilation/perfusion SPECT for diagnosis of pulmonary embolism and other diseases. *International Journal of Molecular Imaging* 2011; Article ID 682949; doi: 10.1155/2011/682949.
- Gutte H, Mortensen J, Jensen CI et al. Detection of pulmonary embolism with combined ventilation-perfusion spect and low-dose ct: head-to-head comparison with multidetector CT angiography. *J Nucl Med*. 2009; 50: 1987–1992.
- Sostman HD, Miniati M, Gottschalk A, Matta F, Stein PD, Pistolesi M. Sensitivity and specificity of perfusion scintigraphy combined with chest radiography for acute pulmonary embolism in PLOPED II. *J Nucl Med* 2008; 48: 1741–1748.
- Miniati M, Pistolesi M, Marini C et al. Value of perfusion lung scan in the diagnosis of pulmonary embolism: results of the Prospective Investigative Study of Acute pulmonary embolism diagnosis (Pisa-PED). *Am J Respir Crit Care Med* 1996; 154: 1387–1393.
- Sostman HD, Pistolesi M. Scintigraphy for pulmonary embolism: too old to rock'n'roll, too young to die? *J Nucl Med*. 2011; 52: 1505–1507.
- Miniati M, Sostman HD, Gottschalk A, Monti S, Pistolesi M. Perfusion lung scintigraphy for the diagnosis of pulmonary embolism: a reappraisal and review of the Prospective Investigative Study of Acute Pulmonary Embolism Diagnosis methods. *Semin Nucl Med* 2008; 38: 450–461.
- Gutte H, Mortensen J, Jensen CV et al. Detection of pulmonary embolism with combined ventilation-perfusion SPECT and low-dose CT: head-to-head comparison with multidetector CT angiography. *J Nucl Med* 2009; 50: 1987–1992.
- Miles S, Rogers K, Thomas P et al. A comparison of single photon emission CT lung scintigraphy and CT pulmonary angiography for diagnosis of pulmonary embolism. *Chest* 2009; 136: 1546–1553.
- Bajc M, Neilly JB, Miniati M et al. EANM guidelines for ventilation/perfusion scintigraphy. *Eur J Nucl Med Mol Imaging* 2009; 3: 1356–1370.
- Suga K, Kawakami Y, Ivanaga HI et al. Automated breath-hold perfusion SPECT/CT fusion images of the lungs. *Am J Roentgenology* 2007; 189: 455–463; doi: 10.2214/AJR.06.1290.
- Freeman LM. Don't bury the V/Q scan: it's as good as multidetector CT angiograms with a lot less radiation exposure. *J Nuc Med* 2008; 49: 5–8.
- Jogi J, Ekberg M, Jonson B et al. Ventilation/perfusion SPECT in chronic obstructive pulmonary disease; an evaluation by reference to symptoms, spirometric lung function and emphysema, as assessed with HRCT. *Eur J Mol Imaging* 2011; 38: 1344–1352; doi: 10.1007/s00259-011-1757-5.
- Jogi J, Palmer J, Jonson B et al. Heart failure diagnostics, based on V/P SPECT pattern and quantitative perfusion gradients. *Nucl Med Commun* 2008; 29: 666–673.
- Gradinscak DJ, Roach PJ, Schembr GP et al. Lung SPECT perfusion scintigraphy: can CT substitute for ventilation imaging? *Eur J Nucl Med Mol Imaging* 2009; 36 (supl 2): S300.
- Bailey D, Roach P, Bailey E et al. Development of a cost-effective modular SPECT/CT scanner. *Eur J Nucl Med and Mol Imaging* 2007; 341: 1415–1426.
- Ollson CG, Bitzen U, Olsson B et al. Outpatient tinzaparin therapy in pulmonary embolism, quantified with ventilation/perfusion scintigraphy. *Med Sci Monit* 2006; 12: P19–13.
- Willowson K, Bailey DL, Baldock C. Quantitative SPECT using CT-derived corrections. *Phys Med Biol* 2008; 53: 3099–3112.
- Goethals I, Dierckx R, Meerleer G. The role of nuclear medicine in the prediction and detection of radiation-associated normal pulmonary and cardiac damage. *J Nucl Med* 2003; 44: 1531–1539.
- Goethals I, Dierckx R, Meerleer G. Lung perfusion SPECT/CT can predict future pulmonary complications prior to radiation therapy in patients with lung cancer. *J Nucl Med* 2003; 44: 1531–1539.
- Zang W, Wang J, Tang M et al. Quantitative study of lung perfusion SPECT scanning and pulmonary function testing for early radiation-induced lung injury in patients with locally advanced non-small cell lung cancer *Exp Ther Med* 2012; 3: 631–635.