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How to perform ventilation/ perfusion SPECT

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Introduction

Ventilation/perfusion scintigraphy is primarily applied for diagnosis of pulmonary embolism, PE, an acute ailment, which should be treated as soon as possible in order to avoid deterioration and potentially death. The referring doctor needs a clear and prompt reply in terms of PE, – Yes! or No! The patient should not be exposed to any danger. Therefore radiation hazards should be reduced to an absolute minimum. An extremely important requirement is that the examination should be feasible in every patient. The time under the gamma camera should be quite short, so that the acute examinations can be performed without seriously perturbing the examination schemes in a busy nuclear medicine department. Most importantly, a method of ventilation/perfusion SPECT, V/P_{SPECT}, should have high sensitivity, specificity. As the majority of patients with suspicion of PE do not have the disease the negative predictive value should be close to 100 %. The design of a method that in an optimal way combines these requisites calls for systematic studies with respect to all these items. The objective of this presentation is to present and discuss issues with respect to how V/P_{SPECT} should be performed.

Principles of V/P_{SPECT}

Imaging of regional ventilation is based upon inhalation of a radioactive gas or aerosol. The actual gas is ^{81m}Kr, which is produced from a generator of rubidium (⁸¹Ru). The gamma energy is 193 keV. Half-life is only 13 seconds. Therefore, inhaled ^{81m}Kr disappears from the alveolar space mainly by decay as exhalation is a slower process. When a patient breaths air with ^{81m}Kr, the regional alveolar ^{81m}Kr concentration will become proportional to ventilation. Access to ^{81m}Kr is limited.

An aerosol consists of liquid or solid particles suspended in gas (air). Particles above 5 micron impact in the upper airways. The commonly used radiolabelled liquid aerosol is ^{99m}Tc-diethylen-tetraaminopentaacetate, ^{99m}Tc-DTPA, in water solution. Maximum size of inhaled droplets should not exceed 2 micron. In patients with obstructive airway disease a predominant central deposition and hot spots may hamper interpretation of ventilation scintigraphy. With the best available nebulisers this problem occurs in few patients.

Technegas® is a particular aerosol of solid graphite particles, generated in a high temperature furnace, with an average diameter of <0.2 micron. Using ^{99m}Tc-Technegas the problem of hotspots in patients with obstructive lung disease is according to clinical experience less than even the best liquid aerosols.

Perfusion scintigraphy is based on i.v. injection of radio-labelled particles causing microembolization within the pulmonary circulation in proportion to perfusion. The particles are macro aggregates of human albumin (MAA), labelled with ^{99m}Tc, 15–100 microns in diameter. They will lodge in pulmonary capillaries and precapillary arterioles. The particle distribution accurately defines regional lung perfusion. A minimum of 60 000 particles is required to obtain uniform distribution of activity reflecting regional perfusion. Normally, about 400 000 labelled particles are injected. Bearing in mind that there are over 280 billion pulmonary capillaries and 300 million precapillary arterioles, the administration of up to 400 000 particles will result in obstruction of only a very small fraction of pulmonary vessels. A reduction in the number of administered particles to between 100 000 to 200 000 particles is recommended for patients with known pulmonary hypertension, right to left heart shunt or after a single lung transplantation.

Radiochemical purity should be determined. As particles tend to settle on standing, the vial should be shaken gently before use. Withdrawal of blood into the syringe should be avoided as this will cause aggregation of MAA particles that may result in perfusion artefacts. The suspension containing ^{99m}Tc-MAA should be given by slow intravenous bolus injection over 30 seconds while the patient breathes at normal tidal volumes. This will ensure that the particles are infused over several respiratory cycles and facilitate uniform distribution within the pulmonary circulation.

V/P_{SPECT} procedure and radioisotope doses

A prerequisite is that V/P_{SPECT} should allow immediate response to the question: PE, Yes or No? This requires a one day protocol. The goal is to perform the whole exam in less than one hour that is possible if ventilation is studied immediately before perfusion. A large field-of-view dual or triple head gamma camera is needed to limit acquisition time.

Optimization of V/P_{SPECT} imaging protocols requires systematic analysis of activities and acquisition times used for ventilation and perfusion, collimators and image matrices as performed by Palmer et al. [1]. A 1 to 4 activity ratio between ventilation and perfusion is optimal using 25-30 MBq for ventilation studies and 100-120 MBq for perfusion studies. Images should be acquired using a 64x64 matrix and a general purpose collimator. 64 projections per each of two camera heads with 10 s each for ventilation SPECT and 5 s each for perfusion SPECT implies a total acquisition time of 20 minutes.

To reduce radiation exposure to the lowest level possible with maintained diagnostic safety is, on the basis of ethical concerns and good medical praxis, a crucial issue. A total activity of maximum 150 MBq for V/P_{SPECT} is less than in previous recommendations, but has proven adequate in animal and clinical studies[2, 3]. The effective dose is thereby reduced to <2 mSv. The absorbed dose to the female breast is 0.8 mGy [4].

Pregnancy, particularly during the first trimester, poses unique circumstances in relation to radiation hazards. In pregnant women, the interpretation of lung perfusion scintigraphy is usually straightforward because of low frequency of co-morbid pulmonary disorders. Therefore, to minimize radiation, a one to two day protocol is suggested. Perfusion-only scans should be performed on day 1, using a reduced dose of ^{99m}Tc-MAA. In most cases PE can be excluded on the basis of a normal perfusion pattern. When the perfusion pattern is abnormal but not diagnostic of PE, subcutaneous low molecular heparin can be given until a ventilation study is performed on day 2, using an activity deposited in the lung of 20-30 MBq. After the first trimester the standard 1 day protocol or the one to two day protocol can be used. During the first trimester the recommended dose for perfusion study (50 MBq) gives a fetal absorbed dose of 0.1-0.2 mGy [5]. The absorbed dose to the female breast is 0.25 mGy.

The V/P_{SPECT} procedure starts with inhalation of the aerosol, followed by ventilation SPECT acquisition. Without patient movement, MAA is injected followed by perfusion SPECT acquisition. During the examination the patient remains in the supine position, carefully maintained between ventilation and perfusion acquisitions. The total immobilization time of 20 minutes is well tolerated even by critically ill patients. The procedure is practical for the staff.

V/P_{SPECT} reconstruction and display

Iterative reconstruction using OSEM (Ordered-Subset Expectation Maximisation) with for example 8 subsets and 2 iterations is recommended. Standard software can be used for this as well as for image presentation in frontal, sagittal and transversal projections as well as for presentation of rotating 3-D images.

A further option is to calculate and display V/P quotient images. Based upon acquisition in which patient is examined without movement between ventilation and perfusion imaging, ventilation background may be subtracted from perfusion tomograms[1]. After normalisation of ventilation to perfusion count rates, a ventilation/perfusion quotient is calculated, V/P_{quotient}. V/P_{quotient} images facilitate diagnosis and quantification of PE extension, particularly in complex cases.

Principles of V/P_{SPECT} interpretation

The fundement behind PE diagnosis is that PE leads to perfusion defects in areas in regions corresponding to the anatomy of the pulmonary end-arteries, in which ventilation is preserved. PE leads to lobar, segmental or subsegmental areas which are unperfused but ventilated.

PE is commonly recognized in more than one area, most likely because emboli fragment when passing through the right heart and main pulmonary arteries. V/P mismatch is not caused exclusively by PE but may be caused by other disorders such as congenital pulmonary vascular abnormalities, veno-occlusive disease, vasculitis, lung cancer or tuberculous mediastinal adenopathy.

Pulmonary arterial circulation can be affected by many diseases in which both ventilation and perfusion are affected such as obstructive airway disease, tumour and pneumonia. The pattern is called V/P match or in the case of predominant ventilation defects reversed V/P mismatch.

Conclusions

V/P_{SPECT} can be performed using commonly available gamma camera systems. Both liquid aerosols and Technegas can be used. The latter is preferred, particularly in patients with airway disease. The time under the gamma camera is only 20 minutes and the total examination time is only 1 hour. Adequate image quality is obtained by choosing proper combination of activities, acquisition times, collimators and matrix. At recommended activities for ventilation and perfusion SPECT the effective dose is only 2 mSv. During pregnancy, a one to two day protocol with perfusion SPECT on day one is recommended further reducing effective and absorbed doses. Ventilation SPECT is rarely needed on day two.

References

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