Evolutionary Approach – from Planar to SPECT/CT Lung Scintigraphy

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Pulmonary embolism, common and potentially lethal condition, is a blockage of the main artery of the lung or one of its branches by a substance that has traveled from elsewhere in the body through the bloodstream. Usually this is due to embolism of a blood clot from the deep veins in the legs, but a small proportion is due to the embolization of air, fat or amniotic fluid. The obstruction of the blood flow through the lungs and the resultant pressure on the right ventricle of the heart leads to the symptoms of PE which include difficulty breathing, chest pain and palpitations. Clinical signs include low blood oxygen saturation and cyanosis, rapid breathing, and a rapid heart rate. Severe cases of PE can lead to collapse, abnormally low blood pressure, and sudden death.

Most patients who succumb to pulmonary embolism do so within the first few hours of the event. Despite diagnostic advances, delays in pulmonary embolism diagnosis are common and represent an important issue. As a cause of sudden death, massive pulmonary embolism is second only to sudden cardiac death.

Diagnosis is based on these clinical findings in combination with laboratory tests (such as the D-dimer test) and imaging studies.

In treatment anticoagulant medication is typically used, including heparin and warfarin, but severe cases may require thrombolysis or surgical intervention like pulmonary thrombectomy.

In patients with a pulmonary embolism, recurrent embolism and death can be prevented with prompt diagnosis and therapy. Unfortunately, the diagnosis is often missed because patients with pulmonary embolism present with nonspecific signs and symptoms.

Chest radiographic findings alone are nonspecific for the diagnosis of pulmonary embolism. However, an adequate chest radiograph is essential to diagnose conditions that can clinically mimic pulmonary emboli and is an important component of the interpretation of ventilation-perfusion lung scans.

Radionuclide ventilation-perfusion imaging, when properly performed and interpreted, is an effective noninvasive procedure for the detection of pulmonary embolus.

Lung perfusion scintigraphy developed because of invention of extracorporeal cardiopulmonary bypass surgery in the 1960s. What was needed was rapid and objective means of establishing the diagnosis. In researching albumin aggregates, Taplin et al. (1961) found that large albumin particles can be sequestered in the pulmonary capillaries after injection. This observation provided a way to image the distribution of pulmonary arterial blood flow and detect pulmonary embolism (Wagner et al. 1964). Thrombolytic therapy, developed in late 1960s, replaced surgery. From this time, planar lung scintigraphy became an important diagnostic tool and has remained so until present days.

Soon was revealed that not only pulmonary embolism, but various types of lung diseases resulted in regional defects in perfusion, implicated that perfusion defect alone did not mean that patient was suffering from pulmonary embolism. The problem of differentiating pulmonary embolism from other lung diseases led to introduction of xenon-133 (Wagner et al, 1968), later replaced with labeled aerosols, in differential diagnosis of pulmonary embolism. Combined use of perfusion and ventilation scintigraphy was able to differentiate between pulmonary embolism and other lung diseases.

The diagnosis of pulmonary thromboembolism by ventilation-perfusion imaging is based on the difference between ventilation and perfusion as result of the obstruction of pulmonary arterial blood flow by the embolus. The 99m Tc-MAA particles are unable to enter the capillary bed distal to the arterial occlusion, so that part of lung supplied by the involved artery appears as a perfusion defect outlined by the normally perfused lung parenchyma. Because ventilation is generally unaffected, the xenon/aerosol images remain normal in the same regions. Because...
of that, the most typical manifestation of the pulmonary emboli is a wedge-shaped perfusion defect with preserved ventilation: the well known ventilation-perfusion mismatch.

While this principle is simple, its practical application can present demanding challenges to the nuclear imaging physician. Much effort has been directed toward defining the language used to describe the findings on ventilation/perfusion imaging as well as the criteria used to translate them into proper diagnostic conclusions.

A perfusion defect is defined as focus of absent or diminished pulmonary activity on perfusion images. Perfusion defect can be segmental or subsegmental. Subsegmental defect further can be defined as large, moderate or small. Perfusion defects can be further classified with respect to their ventilation expression. A mismatch applies to the circumstance in which a perfusion defect is seen to ventilate normally. Segmental mismatches are a hallmark of pulmonary embolism. A mismatch also requires that the chest radiograph be normal in the same portion of the lung.

The interpretation of ventilation-perfusion images involves the determination of the probability of pulmonary embolism based on a set of specific interpretive criteria.

These criteria have evolved over many years of experience, being defined by an extensive project known as the Prospective Investigation of Pulmonary Embolism Diagnosis (PIOPED).

After applying a set of diagnostic criteria to a lung scan, determination of the probability of pulmonary embolism is made. Those categories of probability are high, intermediate, or low probability. A high probability ventilation-perfusion pattern indicates a greater than 80% likelihood of pulmonary embolism, and a low probability pattern confers less than 20% likelihood. Scans that are not considered to be within those two categories are assigned as intermediate probability. Reanalysis of the original PIOPED data has allowed the assignment of a very low probability to a lung scan indicating a less than 10% probability that pulmonary embolism is present.

PIOPED criteria have caused confusion in nuclear and clinical medicine because the utility of a report in terms of “yes” or “no” to the question pulmonary embolism is greater than the usefulness of the probability of PE (if you tell a referring physician that the patient he sent has a probability for pulmonary embolism of between 20% and 80%, you will probably never be asked again).

PIOPED criteria was constantly being refined and further evolved to PIOPED II interpretive criteria which showed that sensitivity of CT alone was only 83%, and the authors concluded that the false negative rate of 17 percent for CTA alone indicates the need for additional information to rule out PE.

CT angiography, which replaced V/Q scanning as the predominant imaging modality for PE diagnosis in the many centers has serious limitations, which include cost, high radiation doses, and inapplicability in patients who have contraindications (eg, reduced renal function, allergy to contrast agents, recent myocardial infarction or ventilator support). In PIOPED II, 1350 of 7284 patients had an elevated creatinine level or were receiving dialysis and 272 patients were allergic to intravenous contrast material. By contrast, v/p scintigraphy has no contraindications and can be performed in almost all patients. Complications do not occur, and the rate of technical errors is close to zero.

In recent years, good but old planar perfusion-ventilation scintigraphy evolved to technologically superior SPECT perfusion-ventilation scintigraphy. Detection of ventilation and perfusion defects at the subsegmental level is possible by planar imaging, but is considerably better by SPECT. In an animal model with artificial subsegmental emboli, the sensitivity of V/P planar scintigraphy was 67% and of V/P SPECT was 93% (Bajc et all.). In clinical studies, Bajc et al. identified 53% more mismatched regions with SPECT.

In comparable studies V/P SPECT increased the specificity for PE from 78% to 96% at similar sensitivities.

With addition of low dose CT and morphologic examination of lung parenchyma, percentage of non diagnostic findings can be reduced to minimum.
References


