Perfusion Lung Scintigraphy for the Diagnosis of Pulmonary Embolism: A Reappraisal and Review of the Prospective Investigative Study of Acute Pulmonary Embolism Diagnosis Methods

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Using the PISAPED Criteria

Perfusion lung scintigraphy is, by definition, an image of the regional distribution of pulmonary blood flow. Therefore, when examining a Q scan, one should ask the following questions: (1) is pulmonary blood flow distributed physiologically? (2) Is there any structural abnormality of the heart, mediastinum, pleura, diaphragms, or chest wall that alters the scintigraphic outline of the lungs? (3) Is there any perfusion defect within the lungs? (4) If so, is the perfusion defect due to embolic occlusion of the pulmonary vessels or is it due to a parenchymal disorder?

The Normal Scan

Under physiologic conditions, the blood flow to the lungs is preferentially distributed to the dependent and dorsal regions . For many years, it has been thought that such preferential distribution is caused by the effect of gravity. Should it be so, there would be a vertical gradient of blood flow from the apex to base of the lung without any ventral-to-dorsal gradient. As shown in Figure 1, however, a ventral-to-dorsal gradient of blood flow is clearly discernible. On the basis of experiments performed during the last 10 years, it appears that the regional distribution of blood flow is primarily dictated by the anatomic configuration of the pulmonary arterial tree that is best described by fractal geometry.[41] and [42] According to PISAPED criteria, a Q scan is rated normal whenever the blood flow distribution, observed after the injection of the radiotracer with the patient in the sitting position, follows a physiological gradient and no abnormalities in the lung shape or true perfusion defects are observed.

The Near-Normal Scan

A number of thoracic extrapulmonary abnormalities may affect the outline of the lung on Q scintigraphy. Such abnormalities are easily seen on the plain CXR, which is a necessary companion to the Q scan. The structural abnormalities that may alter the shape of the lungs include enlarged heart or hilar vessels, widened mediastinum, blunting of costophrenic angles, extensive thickening of the pleura, small pleural effusion (especially intrafissural), elevated diaphragm, or thoracic wall deformity (eg, severe kyphoscoliosis). Enlargement of the heart, which is frequent in clinical practice, creates an impression on the lung parenchyma that is best seen on the anterior, posterior, and left lateral views of lung scintigrams (Fig. 2). In patients with severe left heart valvular disease or long-standing left heart failure, the pulmonary blood flow is often distributed to the upper and anterior regions of the lungs (Fig. 3). Such redistribution is the consequence of an extensive remodeling of the pulmonary vessels in the dependent lung regions, characterized by medial hypertrophy, intimal proliferation and, ultimately, fibrotic occlusion of the lumen.[43] and [44] The reduction of the vascular cross-sectional area in the dependent lung zones causes a redistribution of blood flow that is linearly related to the elevation of pulmonary vascular resistance.[45] In a physiologic sense, any lung scan with a pathologic distribution of pulmonary blood flow, such that shown in Figure 3, should be rated abnormal. However, because there are no obvious perfusion defects, such a scintigraphic pattern is rated near-normal according to PISAPED criteria.

The Abnormal Scan

When perfusion defects are seen on the lung scan, the physician should make every effort to establish whether they are suggestive of PE or are associated with diseases of the lung parenchyma. Since the introduction of Q scintigraphy, it became evident that PE can be differentiated from other lung disorders by the presence of segmental or lobar perfusion defects.[46] and [47] At that time, the use of rectilinear scanners equipped with focusing collimators facilitated the identification of such abnormalities by virtue of the tomographic properties of the technique. With the use of gamma-cameras, the identification of segmental or lobar perfusion defects can be accomplished with the aid of multiple planar projections or by means of single-photon emission tomography. Since the perfusion defects in lung embolism are usually wedge-shaped, any lung scan

showing one or more such defects is rated positive for PE according to PISAPED criteria. Accordingly, the shape of the perfusion defects is far more important than their number or size.

Examples of Q scans suggestive of PE are shown in Figure 4, Figure 5, Figure 6, Figure 7 and Figure 8. In massive PE, such perfusion defects are often associated with multiple areas of overperfusion featuring a wedge configuration (Figure 4, Figure 5 and Figure 6). Such distinct areas of overflow—that were observed in some 80% of the patients with PE in the PISAPED study—are the expression of the redistribution of blood flow

According to PISAPED criteria, any Q defect other than wedge-shaped should be regarded as negative for PE, whether or not there is a matching radiographic abnormality. Clinical conditions that are associated with perfusion abnormalities not caused by PE include pneumonia, lung cancer, alveolar edema, interstitial lung disease, and chronic obstructive lung disease (COPD). Epidemiological surveys in samples of the Italian general population indicate that the prevalence of COPD in subjects ages 50 years or older is approximately 30%.[48] Therefore, when one evaluates lung scans from elderly patients, COPD should be taken into account as a potential cause of the perfusion abnormalities. In this connection, the CXR may prove useful because it provides criteria for diagnosing moderate-to-severe emphysema.[49] Perfusion lung scans from patients with COPD and no obvious emphysema are shown in Figure 9, Figure 10 and Figure 11.

Examples of lung scans from patients with COPD and emphysema of varying degree of severity are given in Figure 12, Figure 13, Figure 14, Figure 15 and Figure 16. In COPD, the Q scan may show a variety of abnormalities ranging from diffuse inhomogeneities to bilateral nonsegmental perfusion defects that are often symmetric in distribution. When emphysema is present, the outline of the lungs is poorly defined, especially along the upper regions. As emphysema becomes extensive, large unperfused areas are seen, which span from the apex to the base of the lung. In the most severe forms, only a small band of perfused lung tissue is left around the heart and over the diaphragms (Figure 15 and Figure 16). Such extensive perfusion abnormalities should not make the physician interpret the scan as nondiagnostic for PE for, if emboli were present, they would be distributed in those regions where the perfusion is still preserved. The scintigraphic diagnosis of PE in patients with COPD is undoubtedly difficult.

However, when the PISAPED criteria are strictly applied, segmental defects can be identified in the context of diffuse perfusion inhomogeneities. An example of PE in COPD is shown in Figure 17. Perfusion defects associated with bilateral pneumonia and lung cancer are displayed in Figure 18 and Figure 19.

Combining Perfusion Scintigraphy With Pretest Probability of PE

The results of prospective studies support the concept that clinical probability assessment is a fundamental step in the diagnosis of PE. The strategy of combining Q scan interpretation with independent evaluation of clinical probability was tested in a management study including 390 patients with suspected PE.[50] The pretest probability of PE was rated according to a standardized clinical prediction model.[51] Pulmonary embolism was considered present in patients with abnormal scans suggestive of PE and a pretest probability >50%. Patients with normal or near-normal scans and those with abnormal scans not suggestive of PE with a pretest probability <10% were deemed not to have PE. All other patients were allocated to pulmonary angiography. All the patients were followed up for 1 year. PE was diagnosed noninvasively in 132 patients (34%) and excluded in 191 (49%). Pulmonary angiography was required in 67 of the 390 patients (17%). Therefore, the diagnostic yield of the noninvasive strategy was 83% (95% CI, 79-86%). The patients in whom PE was excluded had a 1-year thromboembolic risk of 0.4% (95% CI, 0-2.8%). Combining Q scintigraphy with independent assessment of the clinical probability of PE may prove particularly useful in women of childbearing age who may be at risk of breast cancer when exposed to the substantial radiation burden associated with extensive use of CTA.

Perfusion Scintigraphy in the Follow-Up of PE

The rationale of following over time patients with an established diagnosis of PE is 2-fold: (1) to assess the restoration of pulmonary perfusion, and (2) to identify patients with persistent large perfusion defects who may be at risk of developing chronic thromboembolic pulmonary hypertension. Perfusion scintigraphy offers a number of advantages over CTA for this purpose. It is less expensive, entails a substantially lower radiation burden, and provides an overall view of the regional distribution of pulmonary blood flow, thereby permitting the identification of very small perfusion abnormalities. In a recent study, including 320 patients with angiographically confirmed PE, Q scans

were obtained at diagnosis, and at 1 week, 1 month, and 1 year of inclusion.[52] The median extent of scintigraphically detectable pulmonary vascular occlusion at diagnosis was 43% (range, 5-82%). Most of the patients who survived a full year after PE showed near-complete restoration of pulmonary perfusion along with considerable improvement in arterial oxygenation. Only 4 (1%) of the 320 patients with PE at presentation developed chronic thromboembolic pulmonary hypertension. All these patients featured persistent large perfusion defects in sequential scintigrams. Therefore, monitoring the resolution of PE by lung scanning is a practical and relatively inexpensive means to identify patients with persistent perfusion abnormalities who may be at risk of chronic thromboembolic pulmonary hypertension.

Role of CXR

The CXR is considered by most investigators not to be an accurate means of diagnosing PE.[53] Most patients with PE have abnormal CXR, but the CXR changes are generally considered nonspecific. Common findings include consolidation, various manifestations of atelectasis, pleural effusion (usually small), and diaphragmatic elevation. Less common findings include nodules, focal oligemia, proximal pulmonary artery enlargement and acute heart failure. Some diagnostic signs (particularly focal oligemia or changes in proximal pulmonary artery size) can be subtle and difficult to interpret unless high quality comparison films are available.

However, the CXR is an essential component in the evaluation of a patient clinically suspected of having PE. The CXR is needed to establish or exclude clinical mimics of PE such as pneumonia, rib fracture or pneumothorax. It is also essential for adequate evaluation of the lung scintigram, particularly when the V scan is omitted. One should obtain a high quality PA and lateral examination at the same time as the lung scan. Portable AP films are a poor substitute, and if a portable film must be used, the patient's position should be accurately recorded so that account may be made for layering of pleural fluid. Chest radiographs more than a few hours old are also suboptimal.

It has long been thought that the CXR provides information that is complementary and important to the interpretation of the Q scan.[47] This is of particular note with the PISAPED criteria. When using the PISAPED criteria, in examining the CXR, the reader must consider the following items: size and shape of the heart and hilar arteries, position

of the diaphragm, presence or absence of pulmonary parenchymal abnormalities (consolidation, atelectasis, oligemia, edema), and pleural effusion. On evaluating the hilar arteries, attention is paid to the presence of abrupt vascular amputation that gives the hilum a “plump” appearance.[51] Pulmonary consolidations are considered suggestive of infarction if they have a semicircular or half-spindle shape and are arranged peripherally along the pleural surface.[51] Oligemia is considered to be present if, in a given lung region, the pulmonary vasculature is greatly diminished with or without concomitant hyperlucency of the lung parenchyma.[51] Chest radiographs are rated as abnormal if one or more of the following are present: enlargement of the heart or hilar vessels; elevated diaphragm (unilateral or bilateral); pleural effusion (including intrafissural liquid); increased lung density (focal or diffuse); pulmonary edema; oligemia with or without pleonexia in the contralateral lung; consolidation suggestive of infarction; emphysema; fibrothorax.

These observations, instead of being used simply to consider the CXR as abnormal, can be used to increase or reduce the clinical likelihood of PE.[51] Furthermore it has to be stressed that in the PISAPED reading of the Q scan the CXR is not used as a surrogate of the ventilation scan. In fact, the shape of the Q scan defects (wedge shaped or not) that determines the scintigraphic diagnosis is judged irrespective of the radiographic findings in the corresponding lung regions. This prevents the possible increase in nondiagnostic results that could derive from interpreting perfusion defects and radiographic increased density as matching defects (eg, in the modified PIOPED criteria).[27]