39 Pulmonary Nuclear Medicine

Objectives:
1. Define ventilation-perfusion lung scintigraphy.
2. Define the radiopharmaceuticals used in lung perfusion and ventilation scans and the physiologic rationale for this examination.
3. Describe the differences in probability-based and trinary systems of interpretation of ventilation-perfusion lung scans.
4. Describe the principles of quantitative (differential) lung scintigraphy.
5. List the main indications of quantitative (differential) lung scintigraphy.

Ventilation-perfusion (or Quotient; hence, abbreviation V/Q) scan is an imaging technique aimed at interrogating the physiology and, to lesser degree, the anatomy of respective body functions. It is mostly indicated for *pulmonary embolism* (PE) or *thromboembolism*.

Assessment of ventilation is performed following inhalation of either a radioactive gas (e.g., Xenon-133) or aerosol (e.g., ^{99m}Tc-DTPA aerosol dispensed by a nebulizer) through a tightly fitted face mask. It allows for regional assessment of pulmonary airflow. The ventilation part of the V/Q scan is usually done first, as the radiotracer used during ventilation is either eliminated through expiration or given in a small enough activity that the radiotracer used during perfusion overrides the residual activity from the ventilation portion of the study. The perfusion imaging is done following intravenous injection of *^{99m}Tc-macroaggregated albumin* (MAA), which consists of small particles (average size of 15–30 μm). These particles are larger than the pulmonary capillary vasculature (about 7 μm); thus, nearly all radiolabeled particles are filtered out by the lungs during its first pass through in proportion with the regional pulmonary artery blood flow. The test can be performed using planar (the most common method in contemporary practice) or SPECT imaging (Reinartz et al. 2004).

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Perfusion is imaged after an I.V. injection of about 300,000–500,000 ^{99m}Tc-MAA particles. There are 300–500 million alveoli in the lungs that are surrounded by a capillary network. A conservative estimate is that less than 1 in 1,000 capillaries would be occluded, which is generally very safe. Exception is a patient with severe pulmonary arterial hypertension that is associated with marked reduction in the alveoli and capillaries. Blocking additional capillaries with ^{99m}Tc-MAA can precipitate right heart failure in these patients; therefore, the study is contraindicated in severe pulmonary hypertension, and caution is advised in cases with signs of right heart strain. Another contraindication includes hypersensitivity to human albumin products (very rare).

The essential V/Q scan principle for detecting PE is based on detecting perfusion defect(s) with normal ventilation, called *V/Q mismatch*. The larger the perfusion defect and the greater their number, the higher is the probability of PE. At least two large segmental mismatches are needed to be reasonably convinced that the patient has a PE (called *high probability* or *positive scan for PE*). If a perfusion defect is matched by a ventilation abnormality, then the likelihood of PE is low. Such finding reflects airspace-based disease that often causes regional hypoxia-mediated vasoconstriction, which in turn can result in a *matched V/Q defect*. Different patterns on V/Q scan are comprised of variations in size, number, the anatomical distribution of perfusion defects, as well as corresponding chest X-ray (CXR) findings. Those patterns can be grouped in probabilistic interpretational categories that define the likelihood of PE, which include essentially normal or negative perfusion, *very low*, *low*, *intermediate* (or *indeterminate*), and *high probability*. This probabilistic reporting has to be combined with clinical pretest probability in order to estimate the post-test probability of PE, which is often confusing for managing physicians. More recently, a simplified approach was developed where the first three categories are reported as *negative study for PE*, the last category as *positive study for PE*, and the indeterminate as *inconclusive*. This system of interpreting is called *trinary*. Pregnancy is a specific concern as the whole body receives radiation exposure, albeit small, particularly from ^{99m}Tc-DTPA which is cleared into the urinary bladder, which is in close proximity to the uterus. Therefore, the ventilation portion of the examination should be initially omitted in pregnant patients and perfusion done with lowest possible activity. If perfusion images show suspicious defects, ventilation can be done later (Fig. 39.1).

Spiral CT pulmonary angiography (CTPA) supplanted V/Q scanning as the initial diagnostic imaging for PE (Wikipedia Contributors 2013). However, concern has been raised recently that it may be too sensitive, resulting in overdiagnosis and overtreatment. Its major strengths include: (a) readily available around the clock in most hospitals, (b) can be performed quickly, and (c) the interpretation is simple to understand-positive, negative, or indeterminate (usually for technical factors).

The indeterminate or inconclusive V/Q result is least helpful in clinical management and is most likely in the presence of CXR opacities, which is where CTPA should be favored. V/Q scanning may take several hours to obtain, or even longer if

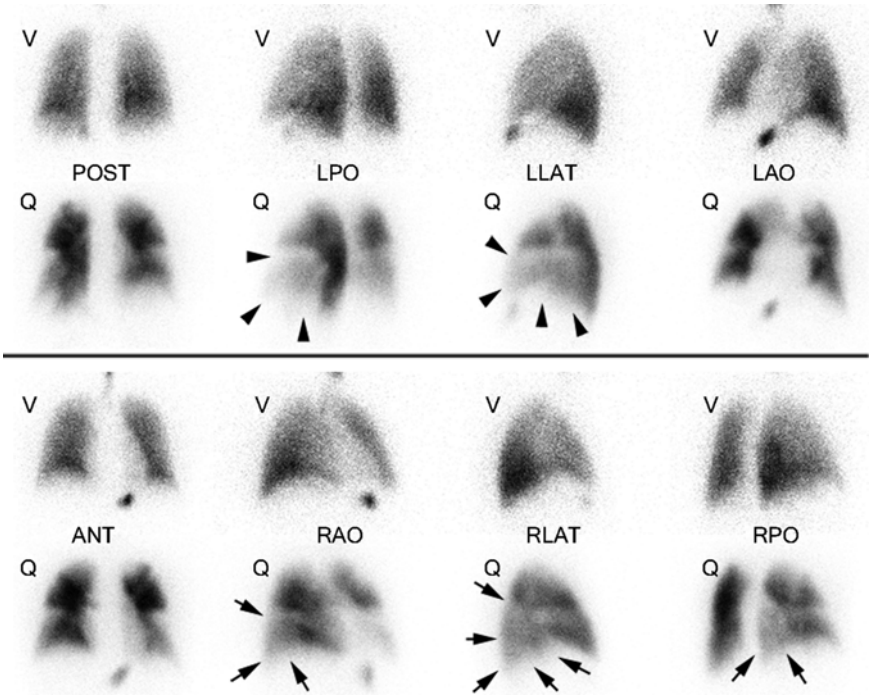

FIGURE 39.1 - HIGH PROBABILITY V/Q SCAN
V/Q scan with findings consistent with "High Probability" or "Positive for PE" interpretation. The chest X-ray was normal. The ventilation (*V*) obtained with ^{99m}Tc-DTPA aerosol are on top and perfusion (*Q*) obtained with ^{99m}Tc-MAA are on the bottom, paired according to the eight standard views: posterior (*POST*), left posterior oblique (*LPO*), left lateral (*LLAT*), left anterior oblique (*LAO*), anterior (*ANT*), right anterior oblique (*RAO*), right lateral (*RLAT*), and right posterior oblique (*RPO*). The ventilation images show normal physiological distribution of activity. The Q images show multiple, large, wedge-shaped perfusion defects. The largest one is severe in count deficit (photopenia) and involves most of the left lower lobe segments and both lingula (*arrowheads*) segments, sparing only the posterior basal segment of the lower lobe. The normal V in those segments defines "mismatch". There is an almost comparable in size mismatched defect that is milder in photopenia and involves all segments of the right lower lobe (*arrows*). There are multiple other smaller defects (not annotated).

ordered after regular work hours, as a technologist often needs to be called in from home and radiopharmaceuticals freshly prepared. Contraindications to CTPA include contrast allergy and renal insufficiency, which is when V/Q scan becomes the preferred modality. Pulmonary hypertension from chronic PE is another circumstance where V/Q may be more sensitive than CTPA (Tunariu et al. 2007). Pulmonary angiography still remains the gold standard for the diagnosis of PE and may be necessary if the diagnosis remains in doubt after V/Q or CTPA scans are performed.

Quantitative lung scintigraphy or differential pulmonary function scan is performed to (1) predict pulmonary function after lung surgery (pneumonectomy or lobectomy) and (2) to quantify asymmetry in patients with compromised pulmonary artery flow, which is usually part of congenital heart syndromes.

The common principle for both indications is based on the fact that perfusion images performed with ^{99m}Tc-MAA are the best correlates for both the lung blood flow and the lung respiratory gas exchange function. It has been shown that performing a ventilation study does not add significant information over perfusion alone in quantifying gas exchange function. This is because the blood flow and gas exchange functions are coupled.

The critical question in patients with lung cancer and abnormal baseline lung function is whether the remaining lung function after surgery would suffice for a

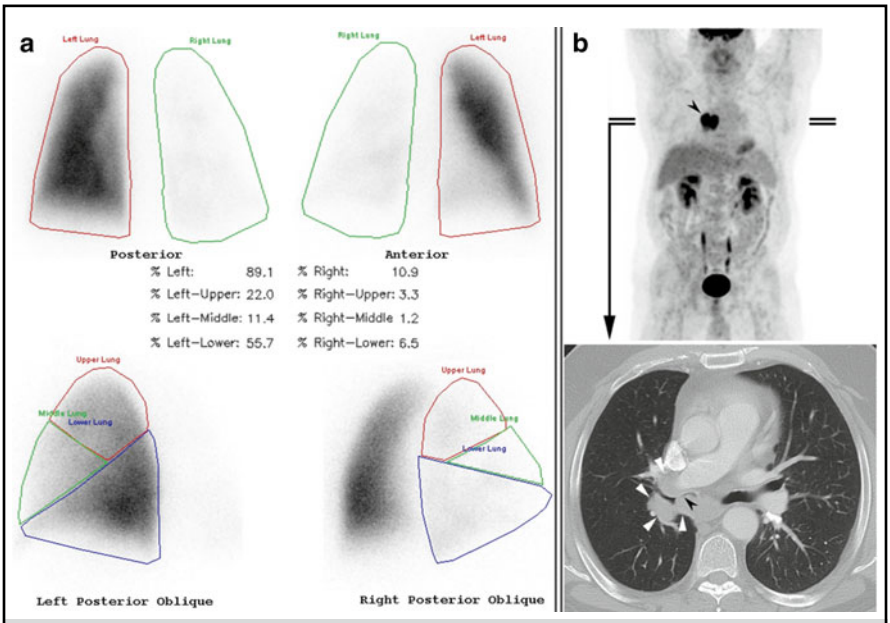

FIGURE 39.2 - APPLICATION OF QUANTITATIVE LUNG FUNCTION SCAN
This is a patient with right lung cancer who had FEV1 of 1.92 L/min, which would be concerning for pneumonectomy clearance and requires further evaluation. (**a**) The perfusion images in the anterior and posterior projections allow for count-based calculations of each lung contribution to lung function. Proportional calculations predict a post right pneumonectomy FEV1 of 1.71 L/min, which is adequate to maintain gas exchange after surgery. The lower panel shows posterior oblique images that allows calculation of individual lobe contributions to the overall pulmonary function and can be used for prediction of post lobectomy function. (**b**) The patient's non-small cell lung cancer was at the right hilum as seen on the top PET/CT MIP image (*arrowhead*) without metastases. The CT slice taken at the level of the mass is shown on the lower panel. The tumor (outlined by *white arrowheads*) compressed the right mainstem bronchus (*black arrowhead*), responsible for the lack of ventilation.

patient to live on, particularly during the perioperative period when the patient is first weaned off ventilator support. The essential lung function parameters in this context which predict complications are preoperative and predicted postoperative forced expiratory volume in one second (FEV_1). The example in Fig. 39.2 demonstrates how predicted postsurgical FEV_1 is calculated.

Pulmonary artery stenosis is often part of congenital heart disease and is typically unilateral. These patients have procedures, such as balloon angioplasty and stenting, which can correct or improve it. The asymmetry in pulmonary blood flow can be detected, quantified, and followed for the surveillance of restenosis using the same left versus right whole-lung quantification on the ^{99m}Tc-MAA images.

References

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