Artifacts and Anatomical Variants Affecting Ventilation and Perfusion Lung Imaging

Seminar in NUCLEAR MEDICINE (2015)

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1395, Mehr 10th
V/Q scan over views:

- Role of radionuclide imaging in PTE diagnosis
- The variants of radionuclide imaging for PTE
- Physiopathology underlying V/Q scan
- Common radiopharmaceuticals used for V/Q scan
- Normal V/Q scan
- Anatomical and artifacts variants in V/Q scan
Role of radionuclide imaging in PTE diagnosis:

- Wagner introduced this technique in 1960
- Powerful tool for Pulmonary disorders survey
- The most prevalent tool for PTE diagnosis
- Safe with high sensitivity and specificity
- Low radiation dose
- Few contraindication
Physiopathology underlying V/Q scan:

- Hypoventilation reduced perfusion to limit deoxygenated blood flow into systemic circulation (compensatory effect to decrease shunt) $\rightarrow$ V/Q match
- Small PTE: cant affect on ventilation $\rightarrow$ V/Q mismatch
- Large PTE: leads to pulmonary infarction, loss of surfactant and pulmonary hemorrhage $\rightarrow$ V/Q match
- Hypoperfusion (PTE) $\rightarrow$ V/Q mismatch +/- match
Common radiopharmaceuticals used for V/Q scan (Ventilation imaging)

- Inert gases:
  1. $^{133}$Xe
     Long half life/ Low energy/ Only one view (posterior) can be taken
  2. $^{81}$Kr
     Good energy/ Short half life/ $^{81}$Rb-$^{81}$Kr generator presents in situ for continuous supply with short life (20 h) /Cost /Availability
Common radiopharmaceuticals used for V/Q scan (Ventilation imaging)

- Inhaled particles: with 3 mechanism
  - Inertial impaction (>10um, large airways)
  - Gravitational sedimentation (~1um, lung peripheries)
  - Brownian diffusion (Submicronic particles)
Common radiopharmaceuticals used for V/Q scan (Ventilation imaging)

- Radioaerosols:
  1. Tc-DTPA in Normal saline:
     2 ways for clearance
     - From alveoli cleared by circulation and kidneys
     - Infection, inflammation and smokers have faster clearance
     - From conducting airways by mucociliary layer
Common radiopharmaceuticals used for V/Q scan (Ventilation imaging)

Small arrow excreted RA (DTPA) in renal pelvic
Large arrow swallowed RA in to stomach
Common radiopharmaceuticals used for V/Q scan (Ventilation imaging)

2. Sulfur colloid
3. Pyrophosphate

They don’t have faster clearance by Inflammation

Long acquisition times of SPECT

Rapid clearance in diseased lung lead to artifacts so

they are not ideal for SPECT ventilation imaging.
Common radiopharmaceuticals used for V/Q scan (Ventilation imaging)

- Particles:
  (99mTc)-Technegas
  size: 160-200nm
  Because of small size, in lack of 81Kr for ventilation SPECT, it can be good choice
Common radiopharmaceuticals used for V/Q scan (Ventilation imaging)

• PET Agents:
  1. $^{68}$Ga ($t_{1/2} = 68$ min), Galligas
     Images like Technegas with advantage of high spatial resolution and high sensitivity
  2. Ne: was used in past and it was like $^{81}$Kr with $t_{1/2} = 17.4$ s
Common radiopharmaceuticals used for V/Q scan (Ventilation imaging)

Normal distribution of radiotracer in ventilation imaging / early wash out for $^{133}$Xe
Common radiopharmaceuticals used for V/Q scan (Ventilation imaging)

COPD patients:

<table>
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<tr>
<th>DTPA</th>
<th>Technegas</th>
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<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
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Common radiopharmaceuticals used for V/Q scan (Ventilation imaging)
Common radiopharmaceuticals used for V/Q scan (Perfusion imaging)

- 99mTc-MAA is almost universally used
- Particles size: 10-90um (average size: 20-40 um)
  Usually 400/000 particles used
- Trap by sixth order or smaller arterial branches
- Particles break down is biphasic:
  Fast component, t1/2 = 0.88 hrs (55%)
  Slow component, t1/2 = 4.6 hrs (0.45)
Normal ventilation imaging:

- Uniform radiotracer distribution
- Less activity at apices and more at bases
- Cardiac outline in ant and post views
- Less activity in medial LLL due to left ventricle (It's not in SPECT images.)
- Reduced ventilation in hilar structures due to large vessels is common in SPECT images.
Normal perfusion imaging:

- Uniform radiotracer distribution
- Less activity in upper lobes and more in bases
- Reduced uptake in Medial LLL due to left ventricle
- Perfusion images is combination of both ventilation and perfusion due to earlier injection of ventilation radiotracer (So the perfusion dose must be greater at least 3-4 times).
Normal perfusion imaging:

large arrow: Heart effect on medial LLL  /small arrow: low uptake of apices
SPECT V/Q imaging

• V/Q SPECT and SPECT/CT is wildly used.
• Static distribution of radioactivity needs over the entire data acquisition
• Dose for ventilation imaging:
  • $25-30 \text{ MBq}$ or higher($40-50$)
• Perfusion imaging: $100-120 \text{ MBq}$ or higher($200$)
• Higher dose is better for older or patients with underlying lung disease for higher quality images
Normal variation of ventilation imaging:

- **Airway disease:**
  Central impaction of tracers
  Hypoventilation in periphery
  Non ventilated area or air trapping
  It is seen with particles especially not gaseous

- **Swallowed radioactivity:**
  It is usually seen in stomach
  Swallowed salivary activity/ Swallow after clearance
  Aerophagy (less common)
Normal variation of ventilation imaging:

Central impaction of tracers in airway disease

Mild COPD with central airways deposition (Technegas)

Severe COPD with central airways deposition (DTPA Aerosol)
Normal variation of ventilation imaging:

swallowed RA in to the stomach
Normal variation of perfusion imaging:

- Sitting instead of supine position:
  During dose administration can lead to decreased activity in upper lobes.

- Difficult / pre-existing venous access:
  Draw back blood in to syringe or in pre-existing access in situ small clots attach to large amount of Tc-MAA and lead to intense uptake on perfusion image (MAA emboli).
Normal variation of perfusion imaging:

MAA emboli (technical error)
Normal variation of perfusion imaging:

Position during injection of radiotracer for perfusion imaging
A: Injection in sitting position
B: Injection in supine position (next day in that patient)
Normal variation of perfusion imaging:

- Elevated left atrial pressure (MR or left ventricle failure):
  - Elevated in pulmonary vein pressure → Diversion of venous flow to upper lobes (especially right upper lobe because of predominance in pulmonary edema) → Intense uptake especially in right upper lobe compared to decreased activity we expect.
Normal variation of perfusion imaging:
Marked upper lobes on perfusion imaging (especially RUL) with uniform ventilation image
Normal variation of perfusion imaging:

Marked RUL on perfusion imaging with uniform ventilation image
Normal variation of perfusion imaging:

Marked upper lobes in SPECT/CT in patients with cardiac failure
Normal variation of perfusion imaging:

Venous congestion in severe MR especially in upper lobes in CXR
Abnormalities of pulmonary circulation:

- Right-to-left intra cardiac shunt
- Intrapulmonary shunt
- SVC syndrome
- IVC syndrome

Extrapulmonary uptake of MAA (kidneys, spleen)

→ Right (pulmonary) to left (systemic) shunt (liver, vertebral bodies, periumblical, thyroid, heart)
→ Systemic vein to portal vein shunt
Abnormalities of pulmonary circulation:

Right to left shunt leads to extrapulmonary uptake
Abnormalities of pulmonary circulation:

- **Scimitar syndrome**: Congenital anomalous for pulmonary vein drainage into IVS
  Perfusion defect in right lower lobe

- **Pulmonary artery compression by lung mass**
  Perfusion defect like emboli
  Rarely mismatch or match defect in V/Q scan

- **Other perfusion abnormality**: Basal segment of LLL perfusion defect (regional steal)
Abnormalities of pulmonary circulation:

CXR in Hilar mass with compression to pulmonary artery and patent bronchus
Abnormalities of pulmonary circulation:

Coronal CT with compression to LUL pulmonary artery and patent bronchus
Abnormalities of pulmonary circulation:

Mismatch LUL defect
Abnormalities of pulmonary circulation:

LUL matching defect
Abnormalities of pulmonary circulation:

Scimitar syndrome / Right lower lobe perfusion defect
Abnormalities affecting both ventilation and perfusion

- Congenital lobar emphysema (over inflation):
  - Obstruction of developing airways
  - Air trapping (ball valve mechanism)
  - Mismatch or sometime match defect of bullae

- Dextrocardia: CT scan for diagnosis
  - Large Match V/Q defect in right lung
Abnormalities affect in perfusion image:

Emphysema (bullae) leads to mismatch defect in right upper lobe that can prove with CT scan.
Abnormalities affecting both ventilation and perfusion

Match defect on right side due to dextrocardia in SPECT CT
SPECT V/Q artifacts:

- The “Rind” artifact:
  Deep inspiration → Even distribution of ventilation agent → lungs come back to tidal volume → micro-atlectasis in dependent (posterior) portion (dynamic process) →
  Increased activity of posterior portion of lungs in ventilation imaging especially in SPECT images with normal perfusion.

Except gases radiotracers like $^{133}$Xe and $^{81}$Kr
SPECT V/Q artifacts:

Left: Rind artifact / Right: PEEP limit Rind artifact
SPECT V/Q artifacts:

Deep inspiration mechanism
SPECT V/Q artifacts:

- Fissure artifact:
  
  Ventilation agents reach to peripheries but perfusion agents accumulate in terminal arterioles. Especially seen in SPECT.
  
  In subtraction, count deficient like halo is seen. Reduced radioactivity in oblique fissure in perfusion (most common in post right lung)/ V/Q Mismatch.
  
  Note: In fissures we have two layers of pleura that leads to doubling this mismatch.
SPECT V/Q artifacts:

Wedge shaped perfusion defect in posterior right lung in horizontal fissure
SPECT V/Q artifacts:

Subtraction of perfusion from ventilation image /rim of removed count due to relative vessels to alveolar space at pleural surface
SPECT V/Q artifacts:

- Better visualization of anatomy
- Higher contrast
- Less noisy
- Large vessels can be seen in perfusion image
- MAA can't accumulate in large vessels so they appear cold on perfusion image. (It is much less evident in ventilation image.)
SPECT V/Q artifacts:

Perfusion defect due to effect of large vessels less evident in ventilation image
“THANK YOU FOR YOUR ATTENTION”
Artifacts and Anatomical Variants Affecting Ventilation and Perfusion Lung Imaging

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Ventilation and perfusion lung imaging continues to be an important technique in the investigation of lung disease, particularly pulmonary emboli. For the most accurate interpretation, a solid understanding of the agents available, underlying physiology, and normal variants is required. A number of ventilation agents are available ranging from true gases to aqueous aerosols and carbon nanoparticles. The addition in recent years of SPECT imaging, although improving the technique, has added to the range of artifacts and variants to be appreciated. In addition, there are uncommon conditions that can affect the scan appearance. A selection of these variants and artifacts is discussed in this article.

Semin Nucl Med 45:373-391 © 2015 Elsevier Inc. All rights reserved.

Introduction

Lung imaging with radionuclides has been an important and effective tool in the investigation of pulmonary emboli since it was introduced by Wagner in the 1960s. The ventilation-perfusion (V/Q) lung scan for suspected pulmonary embolism is still widely used today in many parts of the world. Using modern equipment and radiopharmaceuticals, it is safe and has high sensitivity and specificity (in particular, excellent negative predictive value), low radiation dose, and few, if any, contraindications.

Although the procedure has undergone a number of transformations since its inception, the perfusion tracer [99mTc]-macro-aggregated albumin (MAA) has continued to be the agent of choice to this day. The range of ventilation agents has been much wider: inert gases (initially Xenon-133 [133Xe] and subsequently Krypton-81m[81mKr]), [99mTc]-aerosols, and [99mTc]-Technegas have all been employed and remain in use to varying extents. The choice of ventilation agent will usually be decided by local factors such as availability, cost, and personal preference. More recently, SPECT, SPECT/CT, and PET/CT have provided additional options for the imaging specialist to consider. When interpreting these studies, it is important to have an understanding of the range of normality, common artifacts, and the appearance of specific conditions and congenital abnormalities. The different ventilation agents, in particular, are subjected to different physiological processes leading to differences in distribution that can affect scan appearance and artifacts.

In addition, SPECT and SPECT/CT introduce additional variables owing to the extraprocessing and image coregistration to be considered in the interpretation of V/Q imaging. The use of PET remains very limited and is not covered in detail in this review.

Physiology Underlying Ventilation-Perfusion Lung Scanning

Physiologically, ventilation and perfusion are well matched in normal lungs, and this underpins the application of V/Q lung scanning in medical imaging. If a region of the lung becomes hypoventilated for any reason, deoxygenated blood in the alveolar capillaries would return to the systemic circulation. This “shunt” leads to a decrease in arterial oxygenation. It is a key evolutionary defense that when hypoventilation occurs, the local capillaries constrict blood flow to limit perfusion and,
hence, any shunt. The converse, that is, reduced perfusion with preserved ventilation, is not as compromising an issue in a physiological sense as deoxygenated blood does not return to systemic circulation. The fact that there is ventilation occurring that is unproductive is of little importance to the organism unless very large areas are involved.

In the situation of a pulmonary embolus, it is suggested that a loss of perfusion owing to an embolus is present but that ventilation will be unaffected. In a primary parenchymal process such as chronic obstructive pulmonary disease, reduction in ventilation would be matched by a compensatory reduction in perfusion.

Sadly, reality tends to be more complex. For example, large pulmonary emboli can produce pulmonary infarction with subsequent loss of surfactant and pulmonary hemorrhage leading to matched defects. Hopefully, there will be a mixture of matched and mismatched defects present in these patients, but this phenomenon is a potential contributor to false-negative V/Q study results.

### Ventilation Imaging

Ventilation imaging is surprisingly robust. Most of what is demonstrated on an image is owing to the underlying physiology and flow dynamics rather than technical factors. Naturally, the ventilation agent selected will lead to some variation in the images and associated artifacts owing to differing physical properties. Some differences are highlighted later for the various ventilation agents that have been used.

### Inert Gases

$^{133}$Xe is used as an inhaled gas and has a long physical half-life (5.3 days). Images acquired with this agent represent regional lung volume. It reaches alveolar steady state slowly with an equally slow time to clear, giving information on regional gas retention. Unfortunately, its low $\gamma$ photon energy (80 keV) is suboptimal for the gamma camera and leads to images of poor quality. Owing to the dynamic nature of the inhalation and imaging process, usually only 1 view of the lungs can be acquired.

![Normal planar ventilation scans: generally uniform tracer distribution regardless of agent used. Anterior (A) and posterior (P) projections. $^{133}$Xenon posterior images only: early (left) and washout (right).](image1)

![Galligas ventilation image.](image2)
obtained with $^{133}$Xe, typically in a posterior view. This has led to $^{133}$Xe largely falling out of use in most parts of the world.

$^{81m}$Kr has a very short physical half-life (13 seconds). This demands that a $^{81Rb-81m}$Kr radionuclide generator be present in the scanning room for continuous supply to the subject. Images obtained are representative of wash in as the tracer decays before washout can occur. When delivered constantly, and once steady state is achieved, it provides excellent-quality images that reflect regional ventilation. It is amenable to SPECT imaging. It has a γ photon energy of 193 keV which is nearly ideal for gamma camera imaging. The short half-life means that no residual radioactivity is present during the acquisition of the subsequent perfusion image. $^{81m}$Kr, being a gas with good photon flux and photon energy, probably represents the gold standard agent for ventilation imaging. The main drawback is cost and availability, particularly owing to the short working life of the $^{81Rb-81m}$Kr generator (20 hours).

Figure 3  Ventilation using DTPA aerosol and Technegas in the same patient. Moderate COPD. Note central airways deposition on DTPA images (arrow). COPD; chronic obstructive pulmonary disease. (Adapted with permission from Jogi et al.26)

Figure 4  Normal MAA perfusion images demonstrating the reduction in activity in the left lobe medially due to the heart (large arrow) and mild reduction in the upper lobes best seen on the posterior images (small arrow). AP, anteroposterior.

Figure 5  Images of a ventilation study containing different total counts demonstrating the effect of decreased signal on image quality. The acquired study was partitioned into 6 separate frames. Image A represents the image produced from 1/6th of the total counts, Image B uses ½ of the total counts and Image C uses all available data. One can see the mottling produced by poor count statistics in images A and B compared to Image C. Most severe is image A.
Inhaled Particles and Radioaerosols

Solid and liquid particles that are inhaled can deposit in the lungs. There are 3 main mechanisms of deposition: inertial impaction, gravitational sedimentation, and Brownian diffusion. Which of these occurs is largely dependent on the particle or droplet size.

Particles larger than 10 \( \mu m \) will largely settle in main airways owing to inertial impaction, that is, they are too large to change direction with the moving air column and impact on the branching airways as they divide into smaller generations. The faster the airflow and the larger the particle, usually characterized by the mass median aerodynamic diameter, the more likely the occurrence of impaction. Hence, the large airways, with their faster airflow, are the main site of deposition of large droplets or particles. In patients with airways disease, airflow direction and velocity changes can be more marked and turbulent, enhancing large airways deposition. Particles of smaller size, \( \sim 1 \mu m \), will largely deposit through sedimentation. This occurs under the influence of gravity in regions of low airflow. Typically, this occurs in lung peripheries. Brownian diffusion occurs with submicronic particles. These small particles undergo Brownian motion owing to collision with air molecules. This random movement can lead to some particles impacting on airway walls.

Single-Photon Agents

Various aqueous radioaerosols based on \(^{99m}\)Tc are available for lung ventilation, with \[^{99m}\text{Tc}\]-diethylenetriamine pentaacetate (DTPA) in normal saline being the most widespread in use. \[^{113m}\text{In}\]-DTPA \( (t_{1/2} = 99.5 \text{ minutes}) \) has also been used in a research setting for simultaneous V/Q imaging when used with \(^{99m}\text{Tc}\)-MAA for perfusion. Radioaerosols generally require a nebulizer to create the aerosol. These devices produce droplets with a range of sizes. The smaller the droplet size, the more “gas like” the aerosol. Large droplets will settle out sooner, impacting at the bifurcations of the airways by inertial deposition and producing local aggregations of radioactivity that can interfere with image interpretation and SPECT processing. Better nebulizers can produce droplets with mass median aerodynamic diameter of approximately 2 \( \mu m \). \(^{99m}\text{Tc}\) Radioaerosols require significant patient cooperation and a reasonable inspiratory effort to deliver the aerosols to the lung parenchyma. It should be noted that DTPA radioaerosols can be cleared from the lung by 2 mechanisms: (1) droplets that penetrate deeply in the lung (beyond branches 10-11) can be absorbed through the bronchial epithelium and in the alveoli after which the DTPA circulates in the blood before being removed by the kidneys by glomerular filtration, and (2) those particles depositing on the conducting airways are removed by mucociliary clearance along with the surfactant and mucous by the bronchial cilia. They eventually move up the trachea and are usually swallowed, often shown as radioactivity in the stomach and gastrointestinal tract. The rate of alveolar absorption can be greatly enhanced in infection and inflammation. In normal subjects, alveolar clearance has a half-life of approximately 60-70 minutes. This is accelerated in the setting of smoking and lung inflammation and has been used as an index of inflammatory lung conditions such as human immunodeficiency virus–associated pneumocystis pneumonia. In the setting of inflammation, clearance becomes biphasic with approximately half the radioactivity clearing rapidly, with a half-time clearance of 13 minutes having been demonstrated in smokers. Sulfur colloid and pyrophosphate aerosols labeled with \(^{99m}\text{Tc}\) have also been used. There is little published literature for V/Q scanning in pulmonary embolism using these, though it has been noted that sulfur colloid avoids the issue of absorption in inflammation that can affect DTPA.
aerosol studies. Similar benefits with pyrophosphate imaging have also been suggested.

Whether the radioaerosols are removed by alveolar clearance or mucociliary transport, both effects are deleterious for tomographic imaging with SPECT or PET. A fundamental assumption of tomographic reconstruction is that all views being used to reconstruct an image are of an identical distribution, that is, there is no change in the distribution between the views. With the relatively long acquisition times of SPECT, in particular, and the rapid clearance in the diseased lung, this assumption of a static radionuclide distribution is violated and will lead to artifacts in the reconstructed data. For this reason, radioaerosols are not ideal agents for SPECT ventilation imaging.

Technegas is an ultrafine dispersion of carbon particles in which the Tc atom is trapped as if in a carbon cage. They are nanoparticles produced by the evaporation of a solution of sodium pertechnetate (TcO₄⁻) in a carbon crucible heated to an excess of 2,000°C in argon in a Technegas Generator (Cyclomedica, Sydney, Australia). Particle size is extremely small, on the order of 160-200 nm. Image quality approaches that of 81mKr, particularly in patients with good lung function. It is often said of Technegas that “it goes in like a gas, but sticks to the lining of the airways like an aerosol.” In the absence of a readily available supply of 81mKr, Technegas is an almost ideal agent for ventilation imaging in SPECT, especially as the small particle size permits deep penetration to the non-conducting airways and thus has the desirable characteristic of being a stable distribution throughout the SPECT acquisition.

PET Agents
The use of the PET radionuclide Gallium-68 (68Ga, t½ = 68 minutes) for ventilation imaging has recently been reported after preparation in an unmodified Technegas generator and

Figure 8  Technegas images with mild central airways deposition (top). DTPA aerosol in a patient with severe airways disease (bottom).

Figure 9  Swallowed radioactivity in the stomach (arrow).

Figure 10  Excreted DTPA in renal pelvis. (Swallowed radioactivity in stomach—large arrow). RPO, right posterior oblique; LPO, left posterior oblique.
is therefore referred to as “Galligas.” It produces Technegas-like images but with the advantage of the higher spatial resolution and sensitivity of PET. In the past, $^{19}$Ne has been used in a similar manner to that of $^{81m}$Kr, achieving a steady state owing to its short half-life of 17.4 seconds$^{18}$ (Fig. 1).

**Normal Ventilation**

Regardless of the agent used, normal ventilation is easily recognized with uniform tracer distribution, often with less radiotracer at the lung apices and more at the bases with the cardiac outline being appreciable in both anterior and posterior projections. Apparently reduced radiotracer in the medial left lower lobe typically relates to photon attenuation by the left ventricle (Fig. 2). This is not an issue with SPECT imaging. Reduced or lack of ventilation owing to hilar structures and large vessels is commonly evident on SPECT images.

**Comparative Studies**

There have been relatively few studies comparing $^{133}$Xe and $^{81m}$Kr. These have shown minor differences in distribution, primarily in patients with marked airways disease, but mainly better upper lobe distribution of $^{81m}$Kr. The reason for this is unclear.

There have been a number of studies comparing $^{81m}$Kr and Technegas in both humans and animals. $^{21-25}$ They have uniformly demonstrated that Technegas compares favorably to $^{81m}$Kr in most subjects with some reduction in quality for Technegas compared with $^{81m}$Kr in patients with severe airways disease. Some have noted increased Technegas radioactivity in lower lobes when patients are ventilated erect and have postulated this as a gravitational effect on the Technegas particles or owing to gravity-dependent changes in blood flow.

DTPA aerosols can give adequate images in patients with reasonable lung function but compare unfavorably with gases and Technegas once airways disease is present$^{26}$ (Fig. 3).

**Perfusion Imaging**

$[^{99m}Tc]$-MAA is almost universally used for perfusion imaging. Particle size is nonuniform; however, 90% fall in the 10-90 μm range. The average particle size is 20-40 μm, and there

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**Figure 11** Planar Perfusion Images (A) MAA Images obtained with patient sitting erect. (B) Repeat images the next day with the patient injected supine.

**Figure 12** Focal areas of abnormal uptake due to MAA emboli. Planar (left) and SPECT (right).

**Figure 13** CXR demonstrating venous congestion. CXR, chest x-ray.
should be no particles larger than 150 μm. Particles <10 μm may pass through the lungs and are subsequently phagocytosed by the reticulo-endothelial system. Approximately 400,000 MAA particles are injected for most studies (distributing in a total of 280-300 × 10⁹ pulmonary capillaries). These particles will be trapped by sixth-order and smaller arterial branches. The MAA particle breakdown is reported to be biphasic with a fast component of \( t_{1/2} = 0.88 \) hours (55%) and slow component of 4.6 hours (45%).

Figure 14  Planar images demonstrating marked upper lobe diversion of MAA in the perfusion images to both upper lobes (lower) with uniform ventilation (upper). RAO, right anterior oblique; LAO, left anterior oblique.

Figure 15  SPECT/CT images demonstrate marked upper lobe diversion of MAA in this patient with severe cardiac failure.
Normal Perfusion

Normal MAA images demonstrate uniform pattern of distribution, again with the typical mild reduction in the upper lobes, likely because of reduced lung mass in these areas and the apparent reduction medially in the left lower lobe owing to the left ventricle. It should be noted that, for the technetium-based tracers, the image is actually a composite of ventilation and perfusion owing to residual ventilation agent remaining in the lungs. Hence, the use of 3-4 times the amount of radioactivity in the perfusion injection to reduce the contribution from the earlier administered ventilation agent (Fig. 4).

Image Quality and Image Noise

In many examples in imaging we are frequently required to review images that appear “noisy.” Noise is an unavoidable effect of the statistical nature of radioactive decay underlying our imaging modality. Gamma ray photons strike a surface (ie, the detector) in a random temporal order. Owing to the limited total number of photons (also referred to as “events” or “counts”) acquired, we do not expect juxtaposed pixels in the image matrix to necessarily have an identical number of events even if the 2 regions viewed contain the same amount of radiopharmaceutical. The variation may be owing to real underlying differences in the relative photon flux rate at 2 neighboring parts of the body, differences in attenuation of the photons as they pass through the body to the detector, or because of the random Poisson statistical nature of the decay of radioactive nuclei. We can reduce the relative effect of noise in useful data, however, by increasing the photon flux (more radiopharmaceutical used), by increasing the acquisition time, or by improving technical factors such as camera sensitivity. Whenever we have a low-count study, be it because of reduced administered radioactivity, increased attenuation, or other factors, we will have to contend with a certain amount of “mottle” in the image. In V/Q studies, this will usually be more evident in the ventilation images that contain, by the nature of most V/Q protocols, substantially fewer total number of events than that of the perfusion image (Fig. 5).

Ventilation agents, particularly aerosols, are subject to their own nonuniform distributions, and sufficient particles must be deposited throughout the lungs to give an adequate image. Patients unable to ventilate well will often display noisy images of poor quality. This can be partially mitigated by using...
radioaerosols with smaller particle size, with Technegas being optimal.

The lodging of MAA particles in the pulmonary vasculature is also subject to a statistical, random variation. The number of MAA particles required for an adequate image to overcome quantum effects has been demonstrated to be approximately 60,000. There was no additional benefit when exceeding 150,000 particles. As we give higher activities of MAA to minimize the contribution from the ventilation agent, perfusion images are less likely to be affected by this issue and will be of higher quality.

Reduced counts studies can be done by design such as using reduced administered radioactivity in pregnant patients to decrease the radiation dose to mother and the fetus, or may be because of patient factors such as the inability of patients to ventilate adequately owing to pain or lung disease, photon attenuation, and technical factors such as extravasation of the perfusion agent during injection.

When image processing is applied, such as image subtraction (eg, Q-V), noise tends to be increased as the noise in the images being manipulated is not concordant (ie, being randomly distributed) and therefore the subtraction process will increase the noise in the resultant image.

**SPECT V/Q Imaging**

**Introduction**

SPECT V/Q imaging is becoming more widely used in the investigation of suspected pulmonary emboli. While discussing the relative merits of SPECT and SPECT/CT compared with planar imaging continues, it is appropriate to review common findings and artifacts with this approach. It is important to note that SPECT images are reconstructed images and that optimized methods of data acquisition and SPECT reconstruction should be used. As mentioned previously, SPECT requires a static distribution of radioactivity over the entire data acquisition duration.
Administered Radioactivity

European Association of Nuclear Medicine (EANM) guidelines recommend 25-30 MBq for ventilation and 100-120 MBq for perfusion. The authors prefer higher activities, particularly in older patients where the radiation dose is less relevant and the chance of underlying lung disease higher. We typically aim for 40-50 MBq of Technegas with 200 MBq of MAA in the lungs. This allows for higher quality images.

The EANM methodology will give an effective dose to adults (using Technegas) of approximately 1.6 mSv. Our higher dose protocol gives an effective dose of approximately 3 mSv. A low-dose CT will add to the exposure. In most patients, a “low-dose” CT protocol can be used with 30 mAs and 130 kVp resulting in an average dose of 1.8 mSv in women and 1.1 mSv in men (estimated using CT-Expo\textsuperscript{35}). In larger patients, it may be necessary to increase the beam current to 50 mAs, resulting in a dose of 3.5 mSv.\textsuperscript{36}

SPECT Methodology

Both ventilation and perfusion agents are ideally administered in supine position to avoid gradients seen when administered upright. The patient should breathe tidally during ventilation...
as deep inspiration can lead to increased turbulence, particle impaction, and incidence of some artifacts (described later).

It has been recently demonstrated in SPECT imaging that there is a significant difference in tracer distribution between erect and supine tracer administration, with more uniform radioactivity being produced with the subject in supine position. This effect was most marked in the perfusion study\textsuperscript{37} (Fig. 6).

Similarly during MAA administration, normal tidal breathing is preferred.

EANM guidelines recommend that images be acquired in a $64 \times 64$ matrix, 128 views at 10 seconds per view for ventilation and 5 seconds per view for perfusion. Image reconstruction using an iterative algorithm (eg, OSEM, or Ordered Subset Expectation Maximum) is performed with 8 subsets and 2 iterations.\textsuperscript{38} With higher administered radioactivity, we typically acquire data in a $128 \times 128$ matrix, 120 projections at 12 seconds per projection for ventilation and 10 seconds per projection for perfusion to produce high-count or high-resolution images. Iterative reconstruction is performed with 8 subsets and 4 iterations using a Gaussian filter at 8.5 mm. The images are not attenuation corrected, but resolution recovery is applied (Flash 3D, Siemens Healthcare) (Fig. 7).

### Examples of Variations From Normal Ventilation and Perfusion Patterns

#### Ventilation Imaging

##### Airways Disease

Chronic airways disease leads to altered flow in the bronchi often resulting in central impaction of tracer, regions of reduced ventilation peripherally, and areas of nonventilation or air trapping. The larger the ventilation particle, the greater extent of deposition on bronchi walls as flow is disrupted. The gaseous agents do not have this issue (Fig. 8).

##### Swallowed Radioactivity

Radioactivity is frequently seen in the stomach. This is due to either swallowed salivary activity from DTPA or Technegas impacted in the mouth, removal of the agent via mucociliary clearance and subsequent swallowing, or less commonly, aerophagy during ventilation. This radioactivity is typically well clear of the lung fields and easily identified, as it is mainly

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**Figure 21** CXR demonstrating left hilar mass with compression of the left upper lobe artery and patency of left upper lobe bronchus.

**Figure 22** Coronal CT scan demonstrates that while there is compression of the left upper lobe artery, the left upper lobe bronchus remains patent.
Figure 23  Planar (Left) and SPECT (right) ventilation perfusion imaging demonstrates mismatched left upper lobe defect.

Figure 24  Congenital Lobar Emphysema. Note hyperinflation of left upper lobe. There are matching reductions in ventilation (not shown) and perfusion.
evident on the ventilation study (increased counts with perfusion phase renders this radioactivity less visible) (Fig. 9).

**DTPA Absorption and Excretion**
In patients with inflammation of the lungs, there can be absorption of $^{99m}$Tc-DTPA in the bloodstream. This will be excreted via the kidneys (Fig. 10).

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**Perfusion Imaging**

**Patient Position During Radiopharmaceutical Administration**
As discussed previously in reference to SPECT imaging, image position during radiopharmaceutical administration can affect distribution. Decreased radioactivity in the upper lobes of the lung perfusion scan with the use of $^{99m}$Tc-MAA has been

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**Figure 25** Large matched defect on right. SPECT CT reveals dextrocardia.

**Figure 26** Planar and SPECT slice demonstrating the “rind” artifact.
observed when the patient was sitting at the time of dose administration (Fig. 11).

**MAA Emboli**

In patients with difficult venous access, blood can be drawn back into the MAA syringe and small clots form in the needle or syringe. These can have a high concentration of MAA within them. Alternatively, when using pre-existing venous access, there may be small amounts of thrombus present in situ that can be dislodged during injection of the $^{99m}$Tc-MAA with a relatively large amount of radiopharmaceutical attached. They produce focal areas of intense uptake on the perfusion images (Fig. 12).

**Elevated Left Atrial Pressure**

Patients with mitral valve disease or severe left ventricular failure can have elevated left atrial pressures leading to recruitment of upper lobe (Fig. 13) vessels and diversion of venous flow to the upper lobes. This can be visualized in many cases by increased distribution of MAA particles to the upper zones compared with the usual slight reduction in perfusion seen in these areas (Figs. 14-15).

It has been noted that there is a predominance of pulmonary edema in the right upper lobe in patients with mitral regurgitation. $^{39-41}$ This is demonstrated in Figures 16 and 17, where marked right upper lobe diversion without corresponding left upper lobe changes is seen.

**Abnormalities of Pulmonary Circulation**

**Extrapulmonary Uptake of MAA.** Extrapulmonary uptake of MAA has been reported to have an incidence of 3.7%. $^{42}$ The causes include right-to-left intracardiac shunts, intrapulmonary shunts, and superior vena cava (SVC) syndrome. In SVC syndrome, the SVC is compressed by tumor, forcing venous return from the upper limbs to return via collateral pathways including the azygous system, internal mammary venous system, and the long thoracic venous system connecting to both femoral and vertebral veins. $^{43}$ Drainage can pass through the chest wall and into left pulmonary veins, thereby creating a right-to-left shunt. $^{44-46}$ It has been reported that SVC syndrome (and the similar inferior vena cava syndrome) can lead to systemic vein to portal vein shunts. $^{32}$ Hence uptake can be identified in the liver, vertebral bodies, $^{48}$ periumbilical uptake, thyroid, and heart. $^{49}$

Intracardiac shunts can lead to MAA being able to pass from the right heart or pulmonary circulation to the systemic circulation. The MAA will then distribute in different organs and vascular beds. Typically, they demonstrate renal and splenic tracer distribution. Historically this was used to quantify
right-to-left (and intrapulmonary) shunts by measuring lung radioactivity compared with total body radioactivity (Fig. 18).

**Scimitar Syndrome.** Scimitar syndrome is a rare congenital anomaly that involves partial anomalous right pulmonary venous return to the inferior vena cava. Although the pediatric form can be quite severe, the adult form is often asymptomatic. Although this usually drains the entire lung, in one-third, the scimitar veins drain only the lower portion of the right lung.

The example shown is of a 56-year-old woman who presented with pleuritic chest pain. She initially had a chest X-ray performed, which showed a normal result, and then proceeded to a planar V/Q scan (Fig. 20).

**Pulmonary Artery Compression From Lung Mass.** It is not uncommon to have patients present with dyspnea owing to conditions other than pulmonary emboli. Although these commonly do not produce mismatched defects, a mass compressing a pulmonary artery or branch will produce a perfusion defect that can be indistinguishable from an embolus.

The first example is of a 61-year-old woman who presented with acute dyspnea. The chest X-ray (illustrated later) was initially considered unremarkable, but on closer examination, a left hilar mass is evident (Figs. 20-22).

![Figure 28](image1.png)

*Figure 28* Wedge-shaped perfusion defect involving horizontal fissure at posterior margin of right lung.

![Figure 30](image2.png)

*Figure 30* Left: Ventilation subtracted perfusion images demonstrating rim of removed counts. Right: Image of pleural surface (arrow) demonstrating relative paucity of blood vessels to alveolar spaces.
Other Unusual Perfusion Abnormalities. Perfusion defects have also been reported in cases on anomalous systemic arterial supply to normal basal segments of the left lower lobe of the lung and with the arterio-venous malformation producing a "region steal" phenomenon-induced perfusion defects.

Congenital Abnormalities Affecting Both Ventilation and Perfusion

Congenital Lobar Emphysema or Overinflation

Congenital lobar emphysema is a rare developmental anomaly of the lower respiratory tract that is characterized by hyperinflation of one or more of the pulmonary lobes. The most frequently identified cause of congenital lobar emphysema is obstruction of the developing airway, which occurs in 25% of cases. Airway obstruction can be intrinsic or extrinsic, with the former more common. This leads to the creation of a so-called "ball-valve" mechanism in which a greater volume of air enters the affected lobe during inspiration than leaves during expiration, producing air trapping (Fig. 23).

Dextrocardia

The patient shown in Figure 24 had a large matching V/Q abnormality in the right lung field. The low-dose CT revealed the cause to be dextrocardia.

SPECT V/Q Artifacts

The "Rind" Artifact

One of the most common variants seen in ventilation SPECT imaging is the appearance of a band of increased radioactivity along the posterior (dependent) portion of the lungs. Although it may be subtly present on planar ventilation images, SPECT images demonstrate this much more clearly (Fig. 25).
It is suggested that this may be owing to dynamic changes in lung density or volume occurring during image acquisition. Despite the best of efforts, most patients tend to breathe in to, or close to, total lung capacity during inhalation of ventilation agents. This is less marked in patients who are severely unwell where pain or the effects of their illness may limit deep inspiration.

We hypothesize that the alveoli are evenly distended during deep inspiration with even distribution of the ventilation agent throughout the airways. However, as the lungs return to tidal volumes, there is relatively increased density of alveoli (microatelectasis) in the dependent portions. This change in density can sometimes be seen as a density change in a CT scan. Note that this will not occur when ventilated with $^{81m}$Kr or $^{133}$Xe, being gases. This leads to a nonsegmental zone of increased radioactivity.

To examine this hypothesis, we have performed a study on a small group of normal subjects. The application of positive end expiratory pressure ventilation and imaging the subjects lying prone, rather than supine, led to resolution of this finding, confirming the reversible and dynamic nature of this artifact.

Once there has been a dynamic reduction in volume, the appearances may be compounded by the relatively normal appearance of the perfusion scan as the MAA is usually injected with the patient remaining supine and without re-expanding the posterior lung zones.

### Fissure Artifact

A second common finding is reduced radioactivity, especially on the perfusion image, along the line of the oblique fissure. Again this can be occasionally appreciated on a planar study but is much more obvious on SPECT imaging. This can produce a small mismatch, most commonly in the right lung posteriorly.

The “fissure sign” is more pronounced in the perfusion scan compared with the ventilation scan. It is our suggestion that this is due to a number of factors related to the ventilation and perfusion agents used. The better ventilation agents distribute to the alveolar level, reaching the absolute peripheral margin of the lung, that is, to the pleural surface. The perfusion agent (MAA) reaches the lung via the pulmonary arterial circulation. However, the alveolar capillaries average 5.5 $\mu m$ in size and the mean size of MAA particles is 20-40 $\mu m$. MAA therefore does not reach the alveolar capillaries but largely accumulates in the terminal pulmonary arterioles. In the lung peripheries, we mainly have alveolar spaces bounded by the pleura (which derives its blood supply from the bronchial circulation) and few capillaries. This produces a zone of lung that has radioactivity from the ventilation agent with little pulmonary arterial perfusion. At the lung peripheries, this is rarely appreciated, though when subtraction of the ventilation image from perfusion image is performed, a count-deficient “halo” can sometimes be seen supporting this theory.

Fissures consist of 2 layers of juxtaposed pleura imaged in apposition, thereby effectively doubling the relative area of mismatch.

### Better Visualization of Anatomy

The higher contrast and removal of overlying lung tissue of SPECT compared with planar images permits larger vessels to be visualized. Again, they are more clearly seen on the perfusion images. This is likely due to the higher total number of acquired events, producing less noisy images on the perfusion study. In addition, most large blood vessels in the lung travel adjacent to corresponding bronchi or bronchioles. In the ventilation images, the bronchial structures may contain...
a ventilation agent—in the lumen in the case of a gas and on
the bronchial walls if an aerosol. In the perfusion images, these
large vessels will be devoid of MAA and hence appear “cold”
(Fig. 31).

Ventilation of Bullae

Bullous disease often no longer communicates with the
remainder of the airway system. In this case, we expect to
see a matched defect. However, bullae occasionally are
ventilated to some degree, allowing ingress of gaseous and
particulate agents. When this occurs, a mismatch can be
produced, as the bullae are not perfused
(Fig. 32,33).

Conclusion

Ventilation and perfusion lung scanning continues to be
an important and integral part of the assessment of patients with
lung disease. A solid understanding of the underlying physi-
ology, available agents, and common artifacts allows the most
accurate assessment to be made. In the hands of appropriately
trained, skilled interpreters, V/Q imaging today continues to be
a powerful tool in the assessment of pulmonary disorders.

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