SPECT V/Q with Kr81m gas and Tc99m MAA dual energy imaging

RAD Magazine, 40, 471, 11-12

Bill Thomson
Consultant physicist and head of department

Joseph O’Brien
Principal physicist

Manish Pandit
Consultant in nuclear medicine

Greg James
Senior physicist

Alex Neale
Krypton production manager

Alp Notghi
Consultant in nuclear medicine

Physics and nuclear medicine department, City Hospital, Birmingham

Introduction

Lung SPECT V/Q has now superseded planar imaging as the standard modality.\(^1\)\(^2\) The benefits of SPECT over planar are clear, with sensitivity, specificity and accuracy matching that of computed tomography pulmonary angiography (CTPA).\(^3\)

SPECT V/Q can be carried out with Tc99m MAA for perfusion and Tc99m aerosol for ventilation. However, these two studies must be carried out separately, which involves two administrations and gamma camera acquisitions. The activity of the first part needs to be lower to avoid interference with the second part, which can compromise SPECT image quality. The two SPECT studies then need to be moved and aligned for comparison during reporting.

Krypton-81m gas (Kr81m) however has significant advantages due to the higher gamma energy emission of 191 keV. It is possible to collect the Tc99m MAA and the Kr81m SPECT simultaneously using a single dual energy SPECT acquisition. This gives both the perfusion and ventilation SPECT from one acquisition and all the reconstructed slices are therefore completely aligned. This, coupled with the simplicity of the krypton generator operation, makes the method less operator intensive and increases camera capacity.

There are some technical aspects to the Tc99m/Kr81m SPECT acquisition which are different from the planar technique and these are outlined below. Greater detail on the processes are contained in slide sets from our krypton day school.\(^4\)

Kr81m administration system

The Kr81m generator has the parent radionuclide rubidium-81 (half-life 4.6 hours) with Kr81m gas in secular equilibrium, ie the Kr81m activity on the generator has the same activity as the Rb81. An air pump connected to the generator can release the Kr81m and deliver this to the face mask on the patient via a two way valve. A short length of tubing is connected to each arm of the valve. The patient breathes out through one length of tubing, which keeps any exhaled Kr81m gas away from the camera FOV. The patient breathes in through the other length of tubing which has the air flow from the generator. This ensures that while the patient is breathing out, the Kr81m gas flow from the generator is collecting in the tube and breathed in during the next patient breath. This maximises the efficiency of the Kr81m delivery process.

The Kr81m gas activity consists of an initial bolus of activity equal to the Rb81 activity of the generator. This is initially swept out of the generator when the air flow is switched on. There is then a constant flow of Kr81m gas with an activity of 0.05 x bolus activity per second. With the reservoir system, the patient breathes in the initial bolus activity, and then continues to breathe in the constant Kr81m flow. A fraction of the Kr81m gas in the lungs is lost each time the patient breathes out, but the lung activity quickly reaches a stable value, with small fluctuations due to breathing (figures 1a-c). So the Kr81m activity remains relatively constant in the lungs with normal tidal breathing.

All the Kr81m in the generator is delivered to the patient with a relatively low flow of air (about 0.5-1 litre/minute is ideal) and increasing the flow rate does not increase the Kr81m activity. In fact, it may reduce the Kr81m in the lungs due to losses at the reservoir system.

The Kr81m activity can be quite high in the morning, and may lead to significant downscatter into the Tc99m window. This can be controlled with a volume spacer placed in the Kr81m delivery line. A volume of 100ml can reduce the Kr81m activity by about a third through decay in the spacer. This process allows the downscatter from the Kr81m to be controlled and remain less than 30%. The Kr81m activity reduces with the 4.6 hour half life of the parent so later in the day the spacer can be removed.

Patient procedure

The camera needs to be fitted with a collimator that is suitable for the gamma energy of Kr81m, ie no significant septal penetration. The nuclear fields website\(^5\) can be used to calculate septal penetration for 190keV gammas. A value <5% is considered acceptable.

The patient lies supine on the bed and has the test procedure explained, including the need to relax and breathe normally through the mask. Correct fitting of the mask is important to prevent any leakage, and a range of sizes should be available. An elasticated strap is used to hold the mask firmly on the patient’s face (figure 1a). It is best to fit the mask first without the two-way valve assembly, so that communication with the patient can still take place and they can become familiar with the mask system. The valve assembly is then fitted and the patient is positioned under the detectors with their arms raised above their head (figure 1c). A suitable cushion to rest the arms similar to those used in cardiac studies may be useful. A thin pillow below the patient’s head may be used but it is important that the patient’s head does not tilt forward. This can cause the reservoir system to obstruct the path of the detectors during the scan. If the patient can raise their arms during the SPECT acquisition then this minimises the patient to detector distance. However, it is noted that other centres have kept the patient’s arms down to minimise movement and give greater patient comfort. The effect of any attenuation of the arms is minimal.

First thing in the morning, an initial check of Kr81m downscatter levels is performed by observing the rise in Tc99m count rate after the Kr generator has been turned on...
and the gas has distributed within the lungs (about 10 seconds only). If the downscatter exceeds 30% the spacer is fitted to the generator line. The camera is set to acquire a SPECT acquisition with 60 projections in total (25 seconds each), using a 128x128 matrix, a zoom of 1.0, with a body contoured orbit. The energy windows are set to simultaneously acquire Tc99m and Kr81m using 20% energy windows each. The total scan time is in the order of 15 minutes. The operator is advised to observe the krypton image during the scan, paying particular attention to any count rate drops or leaking gas caused by the mask coming loose (eg patient coughing). However the SPECT reconstruction is not affected by a few such events during a scan. After the scan is completed, the raw data is assessed using cine mode for any artefacts, eg motion. The perfusion and ventilation data are processed simultaneously using the same settings, without any need to realign the data or remove hot spots (Kr81m is a gas and as such does not create hot spots as can occur with Tc99m aerosol agents). Reconstruction is with OSEM (four iterations, 10 subsets) with a 3D Butterworth postfilter. For our GE camera, we use a critical frequency of 0.4 cycles per centimetre with power value of 18.

A derived quotient image of perfusion:ventilation has been recommended to guide image interpretation. This is straightforward to carry out with dual isotope Tc99m and Kr81m image set since all SPECT images are perfectly aligned. However, we have found that the quotient images are less frequently used with reporting experience. Also the scaling associated with the quotient image can mean that mental unmatched perfusion defects in both lungs clearly demonstrates (figure 3). Note the small sub-segmental unmatched perfusion defect at the left base (coronal) which does not highlight on the quotient image.

For display, simple software that allows the perfusion and ventilation slices to be compared side by side and linked for scrolling through is remarkably effective. We use a ‘greyscale’ for image display. Software that provides triangulation adds extra functionality to assess suspicious areas in all three orthogonal views (see figures 4 and 5). Incorporating quotient images with this, as offered by HERMES, provides the most comprehensive display functionality.

**Patient dosimetry**

Patient dosimetry is an important consideration. The ARSAC DRL activity for Tc99m MAA is 200MBq, double that for planar imaging. The Kr81m gas administered for SPECT is also significantly greater than for planar due to the need to administer Kr81m during the whole of the time for SPECT. However the short half life means that radiation dose remains low. Dose values for a Kr81m generator strength of 500MBq are given in **table 1** for the patient dose and for the fetal dose. The breast dose, often a concern for CTPA studies, is also given. The fetal dose is negligible compared to the Tc99m, which means that there is no need to consider carrying out a perfusion-only study first in pregnant patients for any dose saving consideration.

**References**

4. http://www.krypton81m.org.uk/day.htm

**Case 1**

37-year-old female. Short of breath (SOB) for two weeks, 11/40 weeks pregnant, CXR and US normal. Multiple segmental unmatched perfusion defects in both lungs clearly demonstrated (figure 3). Note the small sub-segmental unmatched perfusion defect at the left base (coronal) which does not highlight on the quotient image.

**Case 2**

80-year-old male. Acute SOB, hypoxia, desaturation on exertion, persistent tachycardia. CTPA carried out was negative. This VQ scan carried out next day showed moderate to large peripheral segmental perfusion defects in both lungs to confirm PE (figure 4).

**Case 3**

34-year-old female, SOB, pleuritic chest pain. Several large wedge shaped matched defects in both lungs (figure 5). This case illustrates the benefits of dual isotope images where the perfusion/ventilation slices can be easily compared, even with such complex pathology. The comparable resolution of the kr81m ventilation and the Tc99m perfusion can be seen. In fact, on other slices not shown, there was an unmatched perfusion defect seen in the mid-zone of the right lung to confirm recent PE. The ability from dual energy acquisition to directly compare perfusion and ventilation slices helped considerably in identifying this.

<table>
<thead>
<tr>
<th>Tc99m MAA</th>
<th>Kr81m (% of MAA value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient ED mSv</td>
<td>2.2</td>
</tr>
<tr>
<td>Fetal dose mSv</td>
<td>2.2</td>
</tr>
<tr>
<td>Breast dose mSv</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**TABLE 1**

Dose values for 200MBq Tc99m MAA and Kr81m SPECT (500MBq strength generator).

![](image1.png)

**Figure 1**

(A) shows the elastics strap to hold the mask in place. (B) shows the face mask with the valve assembly in place. (C) shows the patient with the mask and valve assembly positioned under the gamma camera. In practice, the tubing from the valve should extend upwards.
Figure 2
EXCEL model of the Kr81m gas in a patient’s lungs for a 15-minute SPECT study. This assumes a standard breathing pattern and a generator strength of 600MBq. The Kr81m lung contents quickly equilibrate from the initial transient peak of 600MBq to a value of 400MBq, with a breathing pattern superimposed on this. (B) is an expanded timescale, up to 120s, showing the detail of the breathing pattern and the equilibration after the start of the study.

Figure 3
Multiple segmental unmatched perfusion defects in both lungs.

Figure 4
CTPA study negative. Next day SPECT scan showed segmental unmatched perfusion defects in both lungs. Note the cross-hair triangulation which, if available in the software package, can help with interpretation by identifying any defect on all slices.
Figure 5
Multiple matched defects in both lungs. This demonstrates the benefits of automatic registration from dual energy acquisition. Note cross-hair triangulation.