Radionuclide Imaging
MII 3073

Clinical Applications of Radionuclide Imaging
CONTENT

1. Bone scintigraphy
2. Lung scintigraphy
3. Thyroid scintigraphy
4. Renal scintigraphy
5. Liver scan
6. Myocardial perfusion imaging
7. FDG PET scan
BONE SCAN

Indications

- Screening of high risk patients with tumors (breast, lung, prostate or kidney) known to metastases frequently to bone.
- Detection of early osteomyelitis.
- Detection of early avascular necrosis.
- Detection and evaluation of Paget's disease, metabolic bone disease, and other osteopathy disease.
- Detection and evaluation of arthritis and internal joint derangements.
INDICATIONS FOR RADIONUCLIDE BONE SCAN

- Evaluation of bone and joint pain of obscure origin.
- Evaluation following questionable abnormal skeletal radiographs.
- Serially following the course of bony response to therapeutic regimens (radiation therapy, chemotherapy, antibiotic therapy).
- Diagnosis of reflex sympathetic dystrophy.
<table>
<thead>
<tr>
<th><strong>RADIOPHARMACEUTICAL USED</strong></th>
<th>Tc-99m methylene-diphosphonate (MDP)</th>
</tr>
</thead>
</table>
| **PATIENT PREPARATION**     | • Well hydrated.  
• Empty bladder prior to imaging.  
• Inform if you're pregnant. |
| **RADIOACTIVITY ADMINISTERED** | • Intravenous (IV)  
• 600 MBq (15 mCi)  
• 800 MBq (20 mCi) for SPECT  
• Scaled dose based on weight for paediatric patients |
| **TYPE OF COLLIMATOR USED** | Low-energy, high-resolution |
| **IMAGE ACQUISITION**       | • When infection/tumor/mets is to be assessed, a bolus injection is given. 3-phase study is performed.  
• Dual-head camera—scan speed 8–10 cm/min  
• Spot views—minimum 500 kcounts per view |
Images are obtained at specific time periods after isotope injection to demonstrate different physiologic information. Three phases are usually described:

**Phase one:** A dynamic flow study (radionuclide angiogram) consists of images obtained at 1-second intervals for 60 seconds after the intravenous injection of the radiopharmaceutical. The region of interest should be within the camera's field of view.

**Phase two:** Immediately following the angiogram, static (“blood pool”) images are obtained of the specific area or, when the localization of a lesion is not clear, a whole body image can be acquired.

**Phase three:** Delayed images are acquired 2 to 4 hours after injection of radiopharmaceutical.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Name</th>
<th>Time after Injection</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>Radionuclide angiogram (Blood flow)</td>
<td>Immediate</td>
<td>Reflects vascularity</td>
</tr>
<tr>
<td>Two</td>
<td>Blood pool</td>
<td>Few minutes</td>
<td>Reflects soft tissue involvement</td>
</tr>
<tr>
<td>Three</td>
<td>Delayed</td>
<td>2 to 4 hours</td>
<td>Reflects osteoblastic response</td>
</tr>
</tbody>
</table>
Normal appearance: Adult

There is **symmetric distribution of activity** throughout the skeletal system in healthy adults.

- Urinary activity
- Faint renal activity
- Minimal soft tissue activity

**Figure 1.**
Anterior (left) and posterior (right) whole body bone scintigrams obtained in an adult demonstrate normal anatomy.
Figure 2.
Anterior (left) and posterior (right) whole body bone scintigrams obtained in a child demonstrate normal anatomy.

- In children, **intense symmetric uptake in the epiphysis of long bones**, which represent centers of normal growth and hematopoietic production, is usually present.
- The marrow-containing **flat facial bones also demonstrate accumulation of radiotracer in children.**
Figure 4.
Extensive osseous metastases from lung carcinoma. Anterior (left) and posterior (right) wholebody bone scintigrams show multiple, randomly distributed foci of abnormal radiotracer uptake. The foci vary in size and intensity.
Figure 5. Paget disease. Whole-body scintigram demonstrates increased radiotracer accumulation in the proximal right femur and in the deformed and enlarged tibias.
LUNG SCAN

Indications:

• Diagnosis of pulmonary embolism (PE), pulmonary hypertension, or unexplained dyspnea and chest pain.
• Evaluation of regional pulmonary perfusion or ventilation.
• Evaluation of patients with emphysema.
• Carcinoma of the lungs.
• Follow-up after a positive perfusion scan for PE.
LUNG PERFUSION SCAN

• A lung perfusion scan assesses blood flow to the lungs.
• It done to check for the presence of blood clot or abnormal blood flow inside the lungs.
• It frequently performed for patients with a suspected pulmonary embolism (blood clot in the lung).
<table>
<thead>
<tr>
<th>Radiopharmaceutical</th>
<th>▪ 99m Tc MAA (macro-aggregated albumin)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient preparation</td>
<td>▪ Pt in supine or semi-recumbent</td>
</tr>
<tr>
<td></td>
<td>▪ Pt should have chest x ray within 12 to 24 hours of study</td>
</tr>
<tr>
<td></td>
<td>▪ Important to document presence of:</td>
</tr>
<tr>
<td></td>
<td>- right to left cardiac shunt (risk of cerebral emboli)</td>
</tr>
<tr>
<td></td>
<td>- severe pulmonary hypertension</td>
</tr>
<tr>
<td>Injection technique</td>
<td>▪ Slow IV injection is given directly into a vein</td>
</tr>
<tr>
<td></td>
<td>▪ Never draw out blood into syringe as it causes “Hot spots” in the lungs</td>
</tr>
<tr>
<td></td>
<td>▪ Supine position - provide a more even apex-to-base distribution of perfusion</td>
</tr>
<tr>
<td>Activity administered</td>
<td>▪ 80 MBq (2 mCi)</td>
</tr>
<tr>
<td>Collimator</td>
<td>▪ Low energy general purpose</td>
</tr>
</tbody>
</table>
| Image acquisition    | ▪ After the radiopharmaceutical is localized in the lungs, 6 images are made:
|                      |   - Anterior and Posterior            |
|                      |   - Both posterior oblique            |
|                      |   - Both anterior oblique / Both lateral views |
|                      | ▪ At least 200 kcounts per view       |
LUNG VENTILATION SCAN

• 3 common methods:
  – Aerosol Tc-99m
  – Kripton-81m gas
  – Xenon-133 gas
Aerosol Tc-99m scan

ADVANTAGES OF AEROSOL VENTILATION IMAGING

• Aerosol is cheaper and greater availability (radioactive gas has a short half-life and often unavailable)
• Images can be obtained in multiple projections or with SPECT to match those obtained for perfusion imaging

DISADVANTAGE

• Image quality is not good as radioactive gas
<table>
<thead>
<tr>
<th>Radiopharmaceutical</th>
<th>99m Tc-DTPA or 99m Tc-dry particles</th>
</tr>
</thead>
</table>
| Patient preparation         | • Pt should have chest x-ray within 12-24 hours of study  
• Familiarization with breathing circuit including mouthpiece and nose clip. Supplemental O2 may be required |
| Activity administrated to patient | 20 – 40 MBq (1 mCi) |
| Activity in reservoir       | 1.5 GBq (40mCi) |
| Activity in crucible        | 240 MBq (6 mCi) |
| Collimator                  | Low-energy, general purpose (diverging collimator) |
| Image acquired              | Views to match perfusion images 200 counts per view |
81mKripton gas scan

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Half life (T1/2)</td>
<td>13 s</td>
</tr>
<tr>
<td>Photopeak (keV)</td>
<td>81</td>
</tr>
<tr>
<td>Decay</td>
<td>IT( ISOMETRIC TRANSITION)</td>
</tr>
</tbody>
</table>

- The imaging procedures.
  1. 81mKripton gas, produced from a rubidium-81 generator.
  2. 99mTc-labeled human albumin macro-aggregates (MAA) injected into the patient and first perfusion image acquired.
  3. The patient breathes a mixture of 81mKripton in air/oxygen produced by passing a stream of water-humidified air/oxygen through generator.
  4. The ventilation image acquired in the same position with six views which include posterior, anterior, both posterior obliques, and either both anterior obliques or lateral views.
  5. Repeated the procedure after the acquisition of all subsequent perfusion images.
Patient preparation

- Obtained PA and Lateral Radiograph of Chest X-ray before lung ventilation imaging for pulmonary embolism.
- If no changes in signs and symptoms = obtained chest radiograph 1 day before the procedure.
- If have changes in signs and symptoms = obtained chest radiograph 1 hour before the procedure.
- Before administration intravenous of the radiopharmaceutical, the patient should be instructed to cough and take several deep breaths.
- The patient in supine position.
- Patient wear face mask with good seal on mask.
Administered radioactivity

**RADIATION DOSIMETRY - ADULTS**

**Radiation dosimetry - Adult**

<table>
<thead>
<tr>
<th>ACTIVITY ADMINISTERED</th>
<th>6000MBq (150mCi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORGAN RECEIVING THE LARGEST RADIATION DOSE</td>
<td>LUNG</td>
</tr>
<tr>
<td></td>
<td>0.0068mGy/MBq</td>
</tr>
<tr>
<td></td>
<td>(0.025rad/mCi)</td>
</tr>
<tr>
<td>EFFECTIVE DOSE EQUIVALENT</td>
<td>0.05-0.1mSv (5-10mrem)</td>
</tr>
<tr>
<td>STAFF DOSE</td>
<td>0.1 μSv (10 μrem)</td>
</tr>
</tbody>
</table>

**Radiation dosimetry - Children (5 years old)**

<table>
<thead>
<tr>
<th>ACTIVITY ADMINISTERED</th>
<th>0.5-5MBq (0.015-0.15mCi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORGAN RECEIVING THE LARGEST RADIATION DOSE</td>
<td>LUNG</td>
</tr>
<tr>
<td></td>
<td>0.022mGy/MBq</td>
</tr>
<tr>
<td></td>
<td>(0.081rad/mCi)</td>
</tr>
<tr>
<td>EFFECTIVE DOSE EQUIVALENT</td>
<td>0.0023mSv (8.5mrem)</td>
</tr>
</tbody>
</table>
Image acquisition

- 200-300 kcounts to match perfusion image
- The collimator are used are low energy and general purpose.
- The type of collimator is a diverging collimator

**ADVANTAGES**
- Image can be obtained without interference from prior perfusion imaging.
- 99mTc MAA and Kr-81 m imaging allows ventilation and perfusion images obtained without patient repositioned.
- The patient breathes continuously from 81m Kripton generator.

**DISADVANTAGES**
- Short half-life if the Kripton-81m generator.
- Decrease availability of generator
- Increases cost.
# Xenon-133 gas
(Physical and chemical properties)

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>APPEARANCE</strong></td>
<td>Colorless gas sealed in a 2 mL unit dose glass vial.</td>
</tr>
<tr>
<td><strong>ODOR</strong></td>
<td>Odorless.</td>
</tr>
</tbody>
</table>
| **GAMMA PHOTON ENERGY**           | Low (81 keV)  
• inferior image quality and resolution.  
• routinely performed before the pulmonary perfusion imaging. |
| **BOILING POINT**                 | -108°C @ 1 mm. |
| **RADIACTIVITY**                  | 10 or 20 mCi/vial on the calibration date and time. |
| **CONCENTRATION**                 | 5 or 10 mCi/mL on the calibration date and time. |
| **SPECIFIC ACTIVITY**            | >1 mCi/μg of Xenon gas on the calibration date and time. |
| **HALF-LIFE**                     | ~ 5.245 days (5.3 days). |
| **STABILITY**                     | Stable under ordinary of use and storage (Stores at 15°C-30°C). |
# Xenon-133 gas
*(Imaging protocols)*

<table>
<thead>
<tr>
<th><strong>RADIOPHARMACEUTICAL</strong></th>
<th>$^{133}$Xe gas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PATIENT PREPARATION</strong></td>
<td>Familiarization with breathing circuit including mouthpiece and nose clip</td>
</tr>
<tr>
<td><strong>PATIENT POSITION</strong></td>
<td>Erect, seated erect or supine</td>
</tr>
<tr>
<td><strong>ACTIVITY ADMINISTERED</strong></td>
<td>37 MBq (1 mCi) per liter</td>
</tr>
<tr>
<td><strong>COLLIMATOR</strong></td>
<td>Low-energy, general purpose</td>
</tr>
<tr>
<td><strong>IMAGES ACQUIRED</strong></td>
<td>Single view, usually posterior initially. Total study time 600 s, washout starting 300 s into study. Dynamic acquisition of $100 \times 6$s frames</td>
</tr>
<tr>
<td><strong>EFFECTIVE DOSE EQUIVALENT</strong></td>
<td>0.3 mSv (30 mrem)</td>
</tr>
<tr>
<td><strong>STAFF DOSE</strong></td>
<td>0.1 μSv (10 μrem)</td>
</tr>
</tbody>
</table>
Xenon-133 gas
(Procedure)

- Attach a clean face mask and fit the mask tightly on the patient with the elastic halter - ensure the mask is comfortable and no leaks - Allow the patient a few moments to become accustomed to the system while breathing room air.

**IMAGE SEQUENCE:**

1) **First breath:** inspire maximally [1 frame for 20 seconds (Posterior)].

2) **Equilibrium/Washing:** Rebreathe gas in a closed system [3 frames for 30 seconds a frame (Posterior, LPO, & RPO)]. (If Supine study: Do only Posterior wash-in for 60 seconds)

3) **Washout:** breath ambient air [15 frames for 20 seconds a frame (Posterior)].
<table>
<thead>
<tr>
<th>Normal:</th>
<th>The radioactive tracer is evenly distributed throughout the lungs during ventilation and perfusion.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abnormal:</td>
<td>The ventilation scan is abnormal but the perfusion scan is normal. This may mean abnormal airways in all or parts of the lung. <strong>Chronic obstructive pulmonary disease (COPD)</strong> or <strong>asthma</strong> may be present.</td>
</tr>
<tr>
<td></td>
<td>The perfusion scan is abnormal but the ventilation scan is normal. Depending on the difference between the two scans, a pulmonary embolism may be present.</td>
</tr>
<tr>
<td></td>
<td>Both the ventilation and perfusion scans are abnormal. This can be caused by certain types of lung disease, such as pneumonia, <strong>COPD</strong>, or a pulmonary embolism.</td>
</tr>
</tbody>
</table>
EXAMPLE OF IMAGES:
LUNG PERFUSION SCAN

NORMAL

ANTERIOR

POSTERIOR

ABNORMAL

R  L

L  R
Normal and Abnormal Lung Perfusion Scan

NORMAL

ABNORMAL
Normal and Abnormal Lung Ventilation Scan
THYROID SCAN

Indications:
• Multinodular Goiter (MNG)
• Mediastinal Goiter
• Thyroid and neck masses
• Hypothyroidism
• Hyperthyroidism
• Thyroid nodules
• Ectopic thyroid
• Thyroid malignancy
• Thyroglossal duct cyst
• Benign diffuse goiter
• Thyroiditis
Thyroid scan (I0dine-123)

<table>
<thead>
<tr>
<th>Radiopharmaceutical</th>
<th>I-123 sodium iodide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radioactivity administered</td>
<td>Orally in capsule form (100-400 µCi)</td>
</tr>
<tr>
<td>Patient preparation</td>
<td>Fast for 4 hours prior to study</td>
</tr>
<tr>
<td>Type of collimator used</td>
<td>3-6 mm aperture pinhole collimator</td>
</tr>
</tbody>
</table>
| Image acquisition         | • Begin after 4 hours after administrated of radiopharmaceutical.  
• Anterior view – neck with pinhole centered over the thyroid region – pinhole-to-neck distance 4 cm – 100k counts /10 minutes.  
• Anterior image of neck and mediastinum – medium energy parallel hole- 200k/10 minutes (requested). |
# Thyroid scan (Tc-99m pertechnetate)

<table>
<thead>
<tr>
<th>Radiopharmaceutical</th>
<th>Tc-99m Pertechnetate</th>
</tr>
</thead>
</table>
| Radioactivity administered | Through Intravenous  
Adult : 10 mCi  
Pediatric : 140uCi/kg with a minimum dose of 1 mCi |

| Patient preparation | Prior to exam, drink a glass of water to clear Tc99m pertechnetate from the oropharynx and esophagus. |

| Type of collimator used | Pinhole  
140keV with a 20% window |

| Image acquisition | • Begin after 15-20 minutes after administrated of radiopharmaceutical.  
• Anterior view – neck with pinhole centered over the thyroid region – pinhole-to-neck distance 14 cm – 100k counts – 10 minutes.  
• 2\textsuperscript{nd} anterior view – neck with pinhole centered at thyroid region – pinhole-to-neck distance is 4 cm – 200k counts – 10 minutes.  
• Anterior oblique – 20-30° angulation – 4 cm – 200k counts – 10 minutes. |
### Comparison of Radiopharmaceuticals for Thyroid Scintigraphy

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tc-99m pertechnetate</td>
<td>• Less expensive</td>
<td>• Trapped, but not organified</td>
</tr>
<tr>
<td></td>
<td>• More readily available</td>
<td>• Activity in esophagus or vascular structures can be misleading</td>
</tr>
<tr>
<td></td>
<td>• More rapid examination</td>
<td>• Poor image quality when uptake is low</td>
</tr>
<tr>
<td>I-123 iodide</td>
<td>• Better for visualization of retrosternal thyroid tissue</td>
<td>• Higher cost</td>
</tr>
<tr>
<td></td>
<td>• Yields better images when uptake is low</td>
<td>• May be less convenient for patient, as delayed imaging at 24 hr is often used</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Less readily available</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Imaging times are generally longer</td>
</tr>
<tr>
<td>Radionuclide</td>
<td>Advantages</td>
<td>Disadvantages</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| Tc-99m pertechnetate| 1. Study started and finished in 1 day  
2. Tracer inexpensive and readily available | 1. Not all nodules that do not organify iodine (cold nodules) are cold with Tc-99m (discordant nodules)  
2. Uptake value is difficult to obtain and subject to more rapid variability over time  
3. Blood pool structures and salivary glands may interfere with scan interpretation  
4. Requires injection |
| Iodine-123          | 1. The gold standard for documentation of nodule functional status (organification)  
2. Uptake can be readily obtained and is not subject to minute to minute variability  
3. Good target to background images of the thyroid  
4. Oral administration | 1. Usually must be ordered at least 24 hours before the study is begun  
2. Requires 2 visits to nuclear medicine department; first visit to administer isotope, and second visit 24 hours later to perform uptake and/or imaging |
Normal appearance of thyroid scan

- Appearance of normal thyroid gland is narrow-winged butterfly.
- In normal appearance of thyroid gland, there should be no area where the concentration is increased and decreased.
- An area of increase radionuclide uptake may be called a hot nodule or hot spot, that may indicate hyper functioning nodule.
- An area of decrease radionuclide uptake may be called a cold nodule or cold spot, it indicates that the area of thyroid gland is underactive or low functioning.
RENNAL SCAN

Indications:

- Renovascular hypertension
- Renal transplant complications
- Lower urinary tract disorders such as vesico-ureteric reflux
- Pyelonephritic scarring
- Renal perfusion and function
- Obstruction (Lasix renal scan)
- Infection (renal morphology scan)
- Pre-surgical quantitation (nephrectomy)
- Congenital anomalies, masses (renal morphology scan)
- Information about renal size, location and anatomy
Renal scan (Tc-99m MAG3/Tc-99m DTPA)

- This scan is for evaluating tubular function, split renal function, and collecting system drainage.

<table>
<thead>
<tr>
<th>Radiopharmaceutical</th>
<th>$^{99m}$Tc-MAG3 / $^{99m}$Tc-DTPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administered activity for adults</td>
<td>80 MBq (2.2 mCi) / 150 MBq (4 mCi)</td>
</tr>
<tr>
<td>Effective dose equivalent</td>
<td>0.6 mSv (60 mrem) / 1.0 mSv (100 mrem)</td>
</tr>
<tr>
<td>Pediatric activity</td>
<td>Fraction of adult activity, based on body weight and subject to a minimum injected activity.</td>
</tr>
<tr>
<td>Patient preparation</td>
<td>Avoid dehydration; 500 ml oral fluid given 20–30 min before injection</td>
</tr>
<tr>
<td>Collimator</td>
<td>Low-energy, general-purpose</td>
</tr>
<tr>
<td>Images acquired</td>
<td>Posterior dynamic study, 10 second frames for 30 minutes, to obtain renogram. Acquired digital images summed every 2 minutes (15 images in all) to provide visual summary of the study</td>
</tr>
</tbody>
</table>
Renal scan (Tc-99m DMSA)

- $^{99m}$Tc-DMSA scan is for accurate measurement of relative renal function and the diagnosis of renal scarring in the presence of urinary tract infection (UTI).

<table>
<thead>
<tr>
<th>Radiopharmaceutical</th>
<th>$^{99m}$Tc-DMSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Static renal imaging for assessment of relative renal function and pyelonephritic scarring</td>
</tr>
<tr>
<td>Administered activity for adults</td>
<td>80 MBq (2.2 mCi)</td>
</tr>
<tr>
<td>Effective dose equivalent</td>
<td>0.7 mSv (70 mrem)</td>
</tr>
<tr>
<td>Pediatric activity</td>
<td>As for $^{99m}$Tc-MAG3</td>
</tr>
<tr>
<td>Patient preparation</td>
<td>None</td>
</tr>
<tr>
<td>Collimator</td>
<td>Low-energy, high-resolution</td>
</tr>
<tr>
<td>Images acquired</td>
<td>Images should be acquired at approximately 3 hours post-injection, and include anterior, posterior, left and right posterior oblique views. Use appropriate acquisition (hardware) zoom for children</td>
</tr>
</tbody>
</table>
Normal appearance of renal scan
Abnormal appearance of renal scan

Renal scan images of a 46-year-old female patient with a distal left ureteric stenosis and a blocked nephrostomy.
LIVER SCAN

Indications:

• Liver and spleen anatomy (size, position and relative function)
• Hepatic metastases and hepatocellular disease, such as jaundice, cirrhosis and hepatitis
• Focal disease, such as tumors, cysts, and abscesses, in the liver and spleen
• Hepatomegaly or splenomegaly (in patients with palpable abdominal masses)
• Splenic infarcts
• Condition of the liver and spleen after abdominal trauma
Liver scan (Tc-99m colloid)

- Colloids are trapped and then taken up by the reticuloendothelial cells (Kupffer cells in liver).
- Images are acquired 15 minutes after injection.
- Costal margin markers are helpful to assess the position of the liver and also a 10 cm marker may be used for liver size measurement.

<table>
<thead>
<tr>
<th>Radiopharmaceuticals</th>
<th>$[^{99mTc}]$colloid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient preparation</td>
<td>None</td>
</tr>
<tr>
<td>Patient position</td>
<td>Supine</td>
</tr>
<tr>
<td>Activity administered</td>
<td>75 MBq (2 mCi), IV</td>
</tr>
<tr>
<td>Collimator used</td>
<td>Low energy, general purpose</td>
</tr>
<tr>
<td>Images acquired</td>
<td>Anterior, posterior, right and left laterals</td>
</tr>
</tbody>
</table>
Normal appearance of liver scan
MYOCARDIAL PERFUSION IMAGING

Indications:

- Diagnosis of coronary artery disease
  - Presence
  - Location (coronary territory)
  - Severity
- Assessment of the impact of coronary stenosis on regional perfusion
- Help to distinguish viable ischemic myocardium from scar
- Risk assessment and stratification
  - Post-myocardial infarction
  - Pre-operative for major surgery in patients who may be at risk for coronary events
- Monitor treatment effect
  - After coronary revascularization
  - Medical therapy for heart failure or angina
  - Lifestyle modification
## MPI (Tc-99m tetrofosmin/ Tc-99m MIBI)

<table>
<thead>
<tr>
<th>Radiopharmaceutical</th>
<th>(^{99m}\text{Tc tetrofosmin})</th>
<th>(^{99m}\text{Tc-MIBI})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Effective dose equivalent</strong></td>
<td>2 day: 8 mSv (800 mrem) 1 day: 10 mSv (1 rem)</td>
<td>2 day: 10 mSv (1 rem) 1 day: 12.5 mSv (1.25 rem)</td>
</tr>
</tbody>
</table>
| **Activity administered** | 2 day protocol:  
- 400 MBq for stress (10 mCi)  
- 400 MBq for rest (10 mCi)  
1 day protocol:  
- 200 MBq for stress (5 mCi)  
- 800 MBq for rest (20 mCi) | |
| **Patient preparation** |  
- No caffeine for minimum of 12 hours if dipyridamole/adenosine stress being used.  
- Consider fasting, withdrawing anti-anginal and vasodilator therapy.  
- Consider fatty meal/water load after radionuclide.  
- Chest binding | |
| **Collimator** | Low-energy, general purpose | |
| **Images acquired** | 2 day protocol superior but may be impractical.  
- Follow chosen stress protocol.  
- Tomographic acquisition.  
- Image 30–60 min after administration.  
- Gate images if at all possible (8 frames minimum). | |
MPI (Tc-99m tetrofosmin/ Tc-99m MIBI)

• One part of examination is performed with stress and the other at rest.  
  – allowing a comparison of myocardial perfusion to be made.
• If amount of tracer in particular segment is relatively lower on the stress image and then higher at rest, known as a reversible defect, this is taken as showing ischemia
• If there is a fixed defect, this indicates myocardial infarction
• There may also be a mixed pattern as a mixture of infarction and ischemia.
Advantages

• Ability to keep up with blood flows at higher rates and with larger defect sizes at stress imaging.

Reinjection control

• It is an alternative to the standard stress/redistribution protocol.
• This protocol may reduce the number of times the patient needs to be scanned, but for patients with fixed defects, a 24-h scan may still be indicated.
### MPI (Thallium-201 chloride)

<table>
<thead>
<tr>
<th>Radiopharmaceutical</th>
<th>$^{201}$Tl chloride</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity administered</td>
<td>80 MBq (+ 40 MBq for reinjection protocol)</td>
</tr>
<tr>
<td>Effective dose equivalent</td>
<td>18 mSv (1.8 rem)</td>
</tr>
</tbody>
</table>
| Patient preparation        | - No caffeine for minimum of 12 hours if dipyridamole/adenosine stress being used.  
                             |   - Consider fasting, withdrawing anti-anginal and vasodilator therapy.  
                             |   - Chest binding                                                   |
| Collimator                 | Low-energy, general purpose |
| Images acquired            | - Follow chosen stress protocol  
                             |   - Tomographic acquisition  
                             |   - Should not be gated  
                             |   - Stress imaging should start immediately after stress ends  
                             |   - Reinject and reimage as appropriate                       |
Stress protocols

- Demonstrate the blood supply to heart muscle, under stress conditions (detecting CAD).

- 3 types of stress test:
  1. Exercise stress test
     - Treadmill exercise
     - Upright bicycle exercise
  2. Pharmacologic vasodilator stressor (unable to perform adequate exercise due to noncardiac physical limitations)
     - Adenosine
       - Increase in myocardial blood flow
     - Dipyridamole
       - Increases the tissue levels of adenosine by preventing the intracellular reuptake and deamination of adenosine.
  3. Dobutamine
     - Increase in heart rate, blood pressure, and myocardial contractility.

   This includes patients who have contraindications to pharmacologic stressors.
Stress procedure

1. Full informed consent to the technique and associated risks.
2. ECG monitoring is mandatory.
3. Venous access readily available.
4. Patient demographics, clinical history, current medication, and caffeine status should be rechecked.
5. Exercise or alternative stress are then undertaken.
6. Hemodynamic variables are measured at rest and at each stage during the test.
7. The radionuclide is administered at peak stress and in the case of exercise this is continued at a lower level for one to two minutes further.
8. Exercise duration, symptoms, reason for stopping, and ECG changes should be noted.
## Stress protocols

<table>
<thead>
<tr>
<th>Method</th>
<th>Protocol</th>
<th>Radionuclide injection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercise</td>
<td>Bruce protocol</td>
<td>Inject tracer at peak stress and continue exercise for 2 minutes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thallium - Start imaging as soon as possible after administration.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$^{99}$Tc radionuclides - delay for 30–60 minutes to clear splanchnic uptake.</td>
</tr>
<tr>
<td>Adenosine (vasodilator)</td>
<td>140 μg/kg/min for 6 minutes. Short-acting.</td>
<td>At 4 min.</td>
</tr>
<tr>
<td>Dipyridamole (vasodilator)</td>
<td>140 μg/kg/min for 4 minutes. Aminophylline “antidote”</td>
<td>4 minutes after completion of injection. Effects may last 25–30 min</td>
</tr>
<tr>
<td>Dobutamine</td>
<td>Start at 5 μg/kg/min. Increase by 5–10 μg/kg/min every 4 minutes up to 40 μg/kg/min.</td>
<td>At peak stress.</td>
</tr>
</tbody>
</table>
Normal appearance of MPI

A schematic diagram showing three SA sections together with the VLA and HLA sections, which are approximately equivalent to those in the clinical images. The assignment of these segments to coronary territories is demonstrated by the shading (gray, LAD; black, LCX; white, RCA). The septum, lateral wall, anterior wall, and inferior wall of the left ventricle are indicated by “Sep”, “Lat”, “Ant”, and “Inf” respectively. LAD, left anterior descending; LCX, left circumflex; RCA, right coronary artery.
Normal appearance of MPI

Stress (top) and rest (bottom) MPI images from normal male subject.
Abnormal appearance of MPI

Stress (top) and rest (bottom) MPI images from a subject with apical ischemia.
FDG PET SCAN

- FDG: Fluorodeoxyglucose (¹⁸F), an analogue of glucose.
- FDG PET imaging depends on the *in vivo* distribution of the glucose.
  - Tumor cells are generally metabolically active and will take up more sugar (glucose) than normal cells. The more glucose the cells take up, the more the cells light up. PET scans take advantage of this difference to help distinguish active from inactive tumor masses.
- Differences between the uptake and metabolism of FDG compared with unlabeled glucose:
  - Both molecules are transported into cells by the same glucose transporter proteins and phosphorylated by hexokinase.
  - FDG however cannot be further metabolized and is trapped within the cell as a consequence of phosphorylation, whereas glucose is either stored in glycogen or rapidly metabolized.
  - Unlike glucose, FDG is not reabsorbed by the renal tubule and is excreted. Therefore, there is activity in the renal collecting system and bladder.
Schematic illustration for early metabolic pathway of glucose and FDG

EXTRACELLULAR

Cell membrane

INTRACELLULAR

Glucose transporter

Glucose

1

Glucose-6-phosphate

2

Glycolysis

CO₂ + H₂O + Energy

FDG transporter

FDG

1

FDG-6-phosphate

2

**1: hexokinase
2: glucose-6-phosphatase

Schematic illustration for early metabolic pathway of glucose and FDG
FDG-6-phosphate, carries a negative charge ion; $^{18}\text{F}^-$

Ion $^{18}\text{F}^-$ decays to ion $^{18}\text{O}^-$

Ion $^{18}\text{O}^-$ combines with hydronium ion (H$^+$) in its aqueous environment

Glucose-6-phosphate contains harmless non-radioactive ‘heavy oxygen’

Normal glycolysis process

Biochemical pathway of FDG in the living cell
**Patient preparation BEFORE FDG PET imaging**

1. Patients should be fasting for at least 4 – 6 hrs. This must include chewing gum, candies and even glucose syrup based medications such as cough preparations.  
   - Patient who is constantly chewing will have increased muscle uptake.

2. Patients should be well hydrated with water only on the day of the test.  
   - Because of renal excretion, good hydration prior to the study minimizes activity in the collecting system.

3. No glucose-containing IV fluids or enteral or parenteral nutrition for inpatients.  
   - Muscle uptake occurs in nondiabetic patients who are receiving dextrose or lactose in their running intravenous lines.

4. Patients should not exercise strenuously on the day before or on the day of the test.  
   - Exercise will increase glucose metabolism in muscles.

5. In diabetics, moderate to good control is crucial such that blood glucose at the time of the test is below 200mg/dl.  
   - Consequently, hyperglycemia in diabetes will competitively inhibit FDG uptake into both normal tissue and tumor.  
   - Above 200mg/dl, the test cannot be proceed and the patient will refer back to the referring physician for better diabetic control prior to imaging.
1. Patients should avoid being within 10 feet of infants, children, pregnant women, and/or breast-feeding women for the remainder of the day.

2. Patients need to continue drinking water and emptying their bladder for the rest of the day.
   - Hydration and frequent bladder voiding decrease the bladder (critical organ) radiation absorbed dose.
There is increased FDG uptake in both skeletal and cardiac muscle. A PET scan can look like this if the patient ate, had glucose, insulin, or exercised prior to the study possibly hiding metastases.

Multiple abnormal focal areas of uptake are identified that were not apparent on the earlier study. Proper patient preparation is important to optimize lesion detection.
Normal appearance of FDG PET