

# **Procedure Guidelines for Radionuclide Myocardial Perfusion Imaging**

**Adopted by the British Cardiac Society, British Nuclear Cardiology Society,  
British Nuclear Medicine Society**

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## Background

Radionuclide myocardial perfusion imaging uses an intravenously administered radio-pharmaceutical to image myocardial perfusion during stimulation of the perfusion system and at rest. The images are acquired using a gamma camera and tomographic imaging is preferred over planar imaging because of the three dimensional nature of the images and their superior contrast resolution. Comparison of the myocardial distribution of radiopharmaceutical after stress and at rest provides information on myocardial viability, inducible perfusion abnormalities and, when ECG-gated imaging is used, regional myocardial motion and thickening.

Clinical governance now makes it mandatory for practice to be based upon evidence whenever possible.<sup>1</sup> This is best achieved by expert analysis of the evidence and to this end the British Nuclear Cardiology Society (BNCS) in association with the British Cardiac Society (BCS) and the British Nuclear Medicine Society (BNMS) have developed procedure guidelines for emission tomographic myocardial perfusion imaging. The guidelines are intended to assist medical practitioners and other healthcare professionals in recommending, performing, interpreting and reporting single-photon emission computed tomography (SPECT) of myocardial perfusion. They do not cover the benefits or drawbacks of the technique in specific circumstances; neither do they address its cost effectiveness in clinical diagnosis and management nor its potential impact on clinical outcomes.

## 1 Methods of Guideline Development

The writing group was composed of clinicians and scientists from different specialities but all with sub-speciality expertise in nuclear cardiology. The advisory group consisted of nominated representatives of the BNCS, the BNMS and the guidelines committee of the BCS. Every effort was made to avoid conflict of interest from non-clinical relationships, and the final document was approved by both groups.

A systematic literature search of Pub Med/MEDLINE<sup>2</sup> from January 1980 to June 2002 was performed. SPECT imaging was cross-referenced with the following terms to find relevant articles: coronary artery disease, exercise and pharmacological stress, myocardial perfusion radiopharmaceuticals, attenuation correction, artefacts, and ECG-gating. Searches were limited to the English literature. In addition, previous published guidelines were reviewed (ACC / AHA exercise testing guidelines,<sup>3,4</sup> ACC / AHA / ACP-ASIM guidelines for the management of patients with chronic stable angina,<sup>5</sup> American Society of Nuclear Cardiology imaging guidelines for nuclear cardiology procedures,<sup>6</sup> Society of Nuclear Medicine procedure guideline for myocardial perfusion imaging 2.0).<sup>7</sup> The search yielded 350 references and those judged to be most representative are included in this document. Relevant data were summarised by each guideline developer and discrepancies were reconciled by consensus. All recommendations are therefore based on either evidence from clinical studies, previous published guidelines or expert consensus of the writing and advisory groups.

## 2 Indications for Radionuclide Myocardial Perfusion Imaging

- 3.1 To assess the presence and degree of coronary obstruction in patients with suspected coronary artery disease
- 3.2 To aid the management of patients with known coronary heart disease:
  - 3.2.1 to determine the likelihood of future coronary events, for instance after myocardial infarction or related to proposed non-cardiac surgery<sup>8,9,10</sup>

- 3.2.2 to guide strategies of myocardial revascularisation by determining the haemodynamic significance of coronary lesions<sup>11</sup>
- 3.2.3 to assess the adequacy of percutaneous and surgical revascularisation<sup>12</sup>
- 3.3 To assess myocardial viability and hibernation, particularly with reference to planned myocardial revascularisation<sup>13</sup>
- 3.4 Special indications:
  - 3.4.1 to assess the haemodynamic significance of known or suspected anomalous coronary arteries and muscle bridging<sup>14,15</sup>
  - 3.4.2 to assess the haemodynamic significance of coronary aneurysms in Kawasaki's disease<sup>16,17</sup>
  - 3.4.3 to assess the presence of microvascular disease, for instance in diabetes mellitus, left ventricular hypertrophy and syndrome X<sup>18</sup>

## 4 Stressing the Myocardial Perfusion System

### 4.1 Dynamic Exercise

#### 4.1.1 Indication

The main indication for dynamic exercise in the setting of radionuclide myocardial perfusion imaging is the assessment of suspected or known coronary artery disease in patients who are able to perform dynamic exercise to an acceptable workload. In particular, dynamic exercise is the ideal form of stress for patients with suspected or known anomalous coronary arteries, muscle bridging or microvascular disease.

#### 4.1.2 Patient preparation

- i. Withdrawal of medications that may interfere with physiological exercise responses should be considered. In general, for the performance of diagnostic studies, beta-adrenoceptor antagonists and calcium channel antagonists should be discontinued for five half-lives before the test unless medically contraindicated.
- ii. Patients should be instructed to dress appropriately for exercise.
- iii. Fasting is not essential. Whilst many centres routinely fast patients prior to imaging, the advantages of this policy are unproven.

#### 4.1.3 Protocol

- i. Exercise testing must be performed by an appropriately trained healthcare professional. Guidelines for appropriate training are being developed by the BNCS but in the absence of these there must be a local statement of suitable training and experience. If the test is not being performed by a physician, a physician experienced in cardiovascular stress should be available for consultation with an urgency appropriate to the situation as defined in local or national guidelines.<sup>19</sup>
- ii. The healthcare professional supervising the stress should be current in advanced life support and appropriate emergency support should be available.<sup>19</sup>

- iii. Initial evaluation should include relevant medical history (including symptoms and medications, cardiovascular risk factors, and prior diagnostic and therapeutic procedures or interventions), and review of medical records and the physician's referral letter or form. Physical examination may also be required to assess risk of the procedure, particularly if absolute or relative contraindications to dynamic exercise such as left ventricular outflow obstruction or aortic aneurysm are suspected.
- iv. Justification and authorization for performing the test should be confirmed before starting in accordance with the Ionising Radiation (Medical Exposure) Regulations 2000<sup>20</sup> and any local procedures that ensure compliance.
- v. Dynamic exercise can be performed using a treadmill or a bicycle ergometer. Most treadmill protocols for exercise testing include an initial period of warm-up, progressive uninterrupted exercise with increasing workloads in each level until and end point is achieved, and a recovery period. The preferred method is the Bruce protocol.<sup>21</sup> Bicycle ergometer protocols generally involve an initial low workload of 25 watts, followed by increases of 25 watts every 2 minutes until end points are achieved.<sup>3</sup>
- vi. Regardless of the exercise protocol used, an intravenous line should be secured and flushed with 5-10 ml of sodium chloride 0.9% injection to ensure patency before starting the test.
- vii. Haemodynamic parameters (heart rate and blood pressure) and electrocardiogram (ECG) should be monitored at rest and throughout the test and recorded at each stage. Monitoring should continue for 5 minutes after exercise or until changes stabilize, and haemodynamic parameters and ECG are close to baseline. Monitoring with a 12-lead ECG is ideal but a subset of leads is also acceptable provided that the lead(s) monitored are sufficient for the diagnosis of arrhythmias.
- viii. Exercise duration, symptoms, reason for stopping and dynamic ECG changes should be noted.

#### 4.1.4 End points and radiopharmaceutical injection

Exercise should be symptom-limited with patients achieving  $\geq 85\%$  of the age- and gender-maximal predicted heart rate. The radiopharmaceutical should be injected close to peak exercise. The patient should continue exercising if feasible for one minute after thallium-201 injection or for two minutes after technetium-99m perfusion tracer injection.

Exercise testing should be stopped if there is:

- i. ST segment elevation  $>0.1$  mV in leads without Q waves
- ii. a drop in SBP  $>10$  mmHg below baseline or of more than 20% from a previous stage despite an increase in workload
- iii. hypertensive response (BP  $\geq 240/120$  mmHg)
- iv. serious arrhythmias (e.g. VF, VT, frequent and symptomatic VPBs, multifocal VPBs, AF, SVT, second or third degree atrioventricular block and symptomatic bradycardia)

- v. severe angina
- vi. physical signs of peripheral hypoperfusion such as cyanosis or pallor
- vii. central nervous system symptoms such as ataxia, dizziness or near syncope

Horizontal or downsloping ST depression below baseline of 0.2 mV 80 ms after the J point is not necessarily an indication for termination of exercise unless it is progressive or associated with symptoms.

## 4.2 Pharmacological stress

### 4.2.1 Indication

Pharmacological stress is an excellent alternative to dynamic exercise and it is used in many centres as the default form of stress, provided that exercise tolerance, symptoms and ECG changes during dynamic exercise are not required (table 1). It has the advantages of speed, reliability and reproducibility, but the disadvantages of cost and inability to monitor the effect of the stress upon myocardial perfusion directly. Pharmacological stress with vasodilators is the procedure of choice for patients unable to exercise adequately<sup>22,23</sup> and for those with LBBB, RBBB or paced rhythm.<sup>24,25</sup>

### 4.2.2 Patient preparation

- i. *Vasodilator stress.* Patients stressed with the vasodilators adenosine or dipyridamole must abstain from caffeine-containing foods, beverages and medications for a minimum of 12 hours prior to the test.<sup>26,27</sup> Aminophylline and theophylline must be stopped 24 hours before the test.<sup>28</sup> Patients on dipyridamole should discontinue the drug for a minimum of 24 hours prior to vasodilator stress. A detailed explanation of the procedure should be given, outlining possible adverse effects and complications.
- ii. *Dobutamine stress.* Patients should stop beta-adrenoceptor antagonists for five half-lives or at least 24 hours before the test unless contraindicated.<sup>29</sup> A detailed explanation of the procedure should be given, outlining possible adverse effects and complications.

### 4.2.3 Protocol

- i. The stress must be performed by a suitably qualified healthcare professional as for dynamic exercise (see paragraph 4.1.3).
- ii. Initial evaluation of the patient's medical history, examination if appropriate, and justification and authorization for performing the test are mandatory.
- iii. *Adenosine stress.* For administration of adenosine, an intravenous line is required and a 3-way connector should be used to allow tracer injection without interruption of adenosine flow. Adenosine is given as an intravenous infusion at a rate of 140 µg/kg/minute for 6 minutes using an infusion or syringe pump. This may be coupled with submaximal dynamic exercise when tolerated to reduce the frequency and severity of adverse effects associated with vasodilator infusion.<sup>30</sup> If this is the case a bicycle ergometer is preferable to a treadmill because intravenous infusions are easily managed when the patient is relatively steady. Heart rate, blood pressure and ECG should be measured and recorded at baseline and every 2

minutes during the infusion. The radiopharmaceutical is injected 2 minutes before termination of the adenosine infusion or sooner if symptoms or other complications (symptomatic bradyarrhythmias, symptomatic hypotension, severe chest pain, or breathlessness associated with wheezing on chest auscultation) require. Tracer injection as early as 2 minutes after the start of the infusion is probably effective. Symptoms during the test should be recorded.

- iv. *Dipyridamole stress.* Intravenous dipyridamole is infused at a rate of 140 µg/kg/minute for 4 minutes. The infusion can be given manually with care and it can be coupled with submaximal dynamic exercise when tolerated. Heart rate, blood pressure and ECG should be measured and recorded at baseline and every 2 minutes during the infusion. The radiopharmaceutical should be injected 4 minutes after completion of the infusion. Symptoms during the test should be recorded. Dipyridamole causes adverse effects that are similar to those of adenosine, although they are generally more prolonged. Intravenous aminophylline (75-250 mg) may be required to reverse these effects (tables 2 and 3).<sup>31,32,33</sup>
- v. *Dobutamine stress.* Dobutamine infusion is commonly used when dynamic exercised is not feasible and there are contraindications to vasodilator stress. It is administered as an intravenous infusion using an infusion or syringe pump in 3-5 minute stages at incremental doses of 5, 10, 15, 20, 30 and 40 µg/kg/minute.<sup>34</sup> Heart rate and blood pressure should be recorded at the end of each stage and the ECG should be monitored continuously. Side effects may occur during infusion in up to 75% of patients (tables 2 and 3). The radiopharmaceutical should be injected when ≥85% of the age- and gender-maximal predicted heart rate is reached or at 40 µg/kg/minute. The dobutamine infusion can be stopped immediately after tracer injection because its haemodynamic effect continues over the period of tracer uptake by the myocardium. Although atropine is given during dobutamine echocardiography if 85% of maximal predicted heart rate is not achieved, this may not be necessary for perfusion imaging because of the direct coronary dilating effect of dobutamine.<sup>35,36</sup> Dobutamine infusion should be discontinued for the same reasons as exercise testing (see paragraph 4.1.4).

### 4.3 Precautions

The immediate presence of a healthcare professional who is current in advanced life support is required for the duration of all stress procedures. Emergency equipment, medications and support personnel should also be available.

### 4.4 Contraindications

#### 4.4.1 Absolute Contraindications to Dynamic Exercise

- i. recent acute myocardial infarction (less than 4 days)
- ii. left main coronary artery stenosis that is likely to be haemodynamically significant
- iii. unstable angina. Once stabilised, exercise stress can be considered 24 to 72 after chest pain depending upon clinically assessed risk.<sup>37</sup>
- iv. left ventricular failure with symptoms at rest
- v. recent history of life-threatening arrhythmias

- vi. severe dynamic or fixed left ventricular outflow tract obstruction (aortic stenosis and obstructive hypertrophic cardiomyopathy)
- vii. severe systemic hypertension (SBP >220 mmHg and/or DBP >120 mmHg)
- viii. recent pulmonary embolism or infarction
- ix. thrombophlebitis or active deep vein thrombosis
- x. active endocarditis, myocarditis or pericarditis

#### **4.4.2 Relative Contraindications to Dynamic Exercise**

- i. left bundle branch block (LBBB), bifascicular block and ventricular paced rhythms, because dynamic exercise leads to perfusion abnormalities of the septum and adjacent walls in the absence of obstructive coronary disease
- ii. right bundle branch block (RBBB) – inducible perfusion abnormalities in the absence of obstructive coronary disease also occur occasionally and it is advisable to avoid or limit dynamic exercise in these patients
- iii. inability or poor motivation to perform dynamic exercise
- iv. recent exercise ECG with inadequate exercise

#### **4.4.3 Absolute Contraindications to Vasodilator stress**

- i. suspected or known severe bronchospasm
- ii. second and third degree atrioventricular block in the absence of a functioning pacemaker
- iii. sick sinus syndrome in the absence of a functioning pacemaker
- iv. hypotension (SBP <90 mmHg)
- v. xanthines intake in the last 12 hours

#### **4.4.4 Relative Contraindications to Vasodilator stress**

- i. bradycardia of less than 40 beats per minute. Initial dynamic exercise normally increases the rate sufficiently to start the infusion.
- ii. dipyridamole medication taken in the last 24 hours. Initial low dose adenosine infusion with subsequent increase is used in some centres in these circumstances but there is no published evidence to support this practice.

#### **4.4.5 Absolute Contraindications to Dobutamine Stress**

- i. as for dynamic exercise above
- ii. known hypokalaemia

#### 4.4.6 Relative Contraindications to Dobutamine Stress

- i. LBBB, bifascicular block, paced rhythm and RBBB, for the same reason as for dynamic exercise

## 5 Radiopharmaceuticals

Thallium-201 and two technetium-99m labelled radiopharmaceuticals (MIBI and tetrofosmin) are available commercially.

### 5.1 Thallium-201

Thallium-201 is initially distributed after intravenous injection to the myocardium according to myocardial viability and perfusion. It redistributes from this distribution over several hours, thus allowing redistribution images to be acquired that are independent of perfusion and reflect viability alone.

#### 5.1.1 Dosage

The maximum usual dose is 80 MBq for stress and redistribution imaging. An additional 40 MBq can be given at rest for reinjection imaging if redistribution is thought to be incomplete at the time of redistribution imaging or if redistribution is predicted to be slow.<sup>38,39</sup> Such reinjection doses are not normally approved as a routine by the United Kingdom Department of Health's Administration of Radioactive Substances Advisory Committee (ARSAC)<sup>40</sup> and must be given at the discretion of the practitioner in individual cases. Higher doses can be considered on an individual basis in obese patients.

#### 5.1.2 Administration

- i. Thallium-201 should be administered through a secure intravenous line in accordance with local radiation protection practices. If it is given through the side arm of a three-way tap through which adenosine or dobutamine are running, then it should be given over 15-30 seconds to avoid a bolus of the pharmacological stressor being pushed ahead of the thallium. Otherwise it can be given as a bolus injection. The thallium syringe can be flushed with three or four 0.5ml aliquots of either saline or the stressor solution to ensure that the full dose is given.
- ii. If a resting injection is given, for instance in a patient with a severe defect of uptake in the stress images, sublingual nitroglycerine can be administered at least 5 minutes beforehand in order to reduce resting hypoperfusion and to increase the correspondence of the resting images with myocardial viability. Other nitrates such as buccal isosorbide dinitrate may also be used and these are ideally should be given in the supine position to avoid symptomatic hypotension.

#### 5.1.3 Imaging protocols

- i. Different imaging protocols can be followed, depending on clinical indication(s) and local practices: stress-redistribution, stress-reinjection, stress-redistribution-reinjection, stress-reinjection-delayed 24 hour imaging.<sup>41</sup>
- ii. Stress imaging should begin within 5 minutes of stress injection and should be completed within 30 minutes of injection.
- iii. Redistribution imaging should be performed after 3-4 hours of rest.



- iv. In patients with severe perfusion defects in the stress images or if redistribution is thought to be incomplete at the time of redistribution imaging, a resting injection can be given (ideally after sublingual nitrates) with reinjection imaging after a further 60 minutes of redistribution.<sup>42</sup> This protocol is normally sufficient for the assessment of myocardial viability.
- v. Imaging can also be performed 24 hours after injection using a longer acquisition time for the assessment of myocardial viability.

## 5.2 Technetium-99m MIBI and tetrofosmin

After intravenous injection these technetium-99m-labeled radiopharmaceuticals are distributed within the myocardium according to myocardial viability and perfusion. Unlike thallium-201 they have minimal redistribution and so separate injections are required for stress and rest studies. The higher energy of technetium-99m generally leads to better quality images (because of less attenuation and scatter) and permits ECG-gating, which gives additional functional information. However, their uptake as a function of myocardial perfusion is less avid than thallium-201 and so defects may be less profound.

### 5.2.1 Dosage

The maximum usual dose for tomography is a total of 1000 MBq for a one-day protocol (normally divided as 250 MBq and 750 MBq), or 400 MBq for each study of a two-day protocol.<sup>40</sup> Higher doses can be considered on an individual basis by the practitioner, for instance in obese patients.

### 5.2.2 Administration

- i. The radiopharmaceutical should be administered through a secure intravenous line in accordance with local radiation protection practices. The same considerations as described above for thallium-201 apply.
- ii. As with thallium-201, resting injections can be given under nitrate cover and this is important when assessing myocardial viability because the absence of redistribution means that viability is underestimated in areas with reduced resting perfusion.<sup>43,44</sup>

### 5.2.3 Imaging protocols

- i. Different imaging protocols can be followed, depending on clinical indication(s) and local practices: one-day stress-rest, one-day rest-stress, two-day (especially for obese patients)
- ii. Imaging should begin 30-60 minutes after injection to allow for hepato-biliary clearance with longer delays required for resting images and for stress with vasodilators alone because of the higher liver uptake.
- iii. A fatty meal can be given between injection and imaging to aid clearance of tracer from the liver and gall bladder. The value of this manoeuvre is uncertain and it may be counter-productive if there is retrograde passage of tracer from duodenum to stomach or if the tracer reaches the transverse colon.<sup>45,46</sup>

## 6 Image Acquisition

### 6.1 Patient Positioning

- i. The patient should be supine with both arms above the head and supported in a comfortable position. Knee support is also helpful and patient comfort is essential to minimise motion. Prone imaging has been used in some centres to reduce the incidence of inferior attenuation artefact<sup>47</sup> but it can produce anterior artefacts and is not recommended for use alone.
- ii. Female patients should be imaged with chest bands to minimise breast attenuation and to ensure reproducible positioning during later image acquisition. This can however increase attenuation depending upon how the bands are applied and careful attention to technique is required when the breasts are strapped.<sup>48</sup> Chest bands can also be used in males to reduce motion.

### 6.2 Acquisition parameters

- i. Tomographic imaging with a single or dual-head gamma camera is commonly performed over a 180° rotation from RAO 45° to LPO 45°. With a dual-headed camera the heads should ideally be at 90° to each other for a 180° rotation. A circular or non-circular orbit can be used according to preference.<sup>49</sup>
- ii. Low-energy general purpose collimation should be used for thallium-201 and high-resolution collimation for technetium-99m tracers.<sup>7</sup>
- iii. A 20% energy window at 72 and 169 keV for thallium-201 and 140 keV for technetium-99m-labeled radiopharmaceuticals should be selected.
- iv. The acquired pixel size should be in the region of 6mm.<sup>6</sup> A zoomed acquisition can be used depending upon camera dimensions but care must be used that the patient lies within the field of view in all projections.
- v. A step-and-shoot acquisition with 32 or 64 stops separated by 3°-6° or a continuous acquisition can be used. The duration of acquisition at each stop depends partly on the protocol, dose of radiopharmaceutical and patient size. Typically, for a 90° dual-headed camera acquiring 64 images (32 projections) the time per projection would be 20 seconds for stress thallium-201, 25 seconds for redistribution thallium-201, 25 seconds for 250 MBq stress technetium-99m acquisition, and 20 seconds for a non-gated 750 MBq (plus preceding stress injection) rest acquisition. Total acquisition times of longer than 20-30 minutes can be counterproductive as they increase the likelihood of patient motion.<sup>6</sup>
- vi. ECG-gating, particularly with technetium-99m-labeled radiopharmaceuticals, can be performed with placement of radiolucent electrodes and a device for gating. For accurate calculation of left ventricular ejection fraction and volumes, 16 frames per cycle should be acquired.<sup>50,51</sup>
- vii. Planar images can be acquired prior to the tomographic acquisition to determine the lung-to-heart ratio although qualitative or quantitative assessment of lung to heart ratio can be made from the tomographic acquisition.<sup>7</sup>

- viii. The planar projection images should be reviewed immediately after acquisition to check for unacceptable motion or other source of artefact such as foreign objects or motion of the heart outside the field of view in some projections.<sup>7</sup>

## **7 Image Processing**

### **7.1 Reconstruction**

- i. Filtered back projection using Butterworth and Hanning filters is the most common method of reconstruction. Cut-off frequencies of 0.5 and 0.75 respectively are normally chosen, and these should be the same for each patient and should not be altered to compensate for low-count images in order to maintain consistency of appearance.<sup>6</sup>
- ii. Iterative reconstruction is preferred if attenuation correction has been performed and it can also be used without attenuation correction.

### **7.2 Reorientation**

- i. The long axis of the left ventricle is defined from the apex to the centre of the mitral valve and definition of the axis can be manual or automatic. Automatic definitions should be checked and adjusted if necessary. The definition should be consistent in both stress and rest studies bearing in mind that the orientation of the ventricle may change slightly between acquisitions.
- ii. The transverse tomograms are reoriented into three sets of oblique tomograms: (1) short axis (perpendicular to the long axis of the left ventricle), (2) vertical long axis (parallel to the long axis of the left ventricle and to the septum), and (3) horizontal long axis (parallel to the long axis of the left ventricle and perpendicular to the septum).

### **7.3 Image Evaluation**

The reconstructed tomograms should be inspected immediately after acquisition by an operator or practitioner in order to identify technical problems that might require repeat acquisition. These might include:

- injection site or external objects passing across the heart
- patient motion
- inaccurate ECG-gating
- problems related to the detector(s), such as drift in energy window and artefact(s) generated by transition between the two detectors.
- inappropriate collimation or energy windows.

### **7.4 Image Display**

- i. Stress and rest images should be appropriately aligned and presented in a format that allows ready comparison of corresponding tomograms, such as interactive displays that triangulate the three planes or display the full set of tomograms.

- ii. Each set of tomograms should be displayed using a window maximum that corresponds to the maximum within the myocardium in each set. Displays that set the maximum of the window to the maximum of each tomogram and those that use the same maximum for stress and rest images should not be used. Care should be taken if the maximum lies outside the myocardium and manual adjustment or masking of extracardiac activity may be required. The lower end of the display window should be set to zero and background subtraction should be avoided. Neighbouring pairs of tomograms can be summed for display according to local preference.<sup>52</sup>

## 7.5 Attenuation Correction

A number of techniques have been developed for correcting emission tomograms for attenuation, in an effort to reduce or eliminate attenuation artefact. Many of these incorporate additional corrections for scatter and for depth-dependent resolution recovery. Although initial results are encouraging,<sup>53</sup> each method behaves differently and none overcomes artefact entirely, some even introducing new forms of artefact from overcorrection. The effectiveness of these techniques in routine clinical practice is currently uncertain. They should currently be used only in experienced centres and preferably as part of a formal evaluation of their value. Corrected images should not be used without review alongside the uncorrected images.

## 8 Image Interpretation

### 8.1 Review of Clinical Details

- i. It can be helpful initially to review the images without reference to clinical information in order to decide upon major features, and then to modify the opinion and decide upon minor features if necessary after review of the clinical information. Attention should be paid to the patient's height, weight and chest size as these may influence the degree of attenuation and quality of the study, and also to what findings would be expected from the clinical information. Unexpected findings are more likely to be artefactual.
- ii. The adequacy of stress should be noted as well as the symptoms and haemodynamic observations during stress. It is helpful to report together with the individuals who took the history, stressed the patient and/or acquired the images since symptoms and other observations during stress can influence reporting.

### 8.2 Review of cine raw data

Before interpreting the tomograms, the stress and rest projection data should be inspected alongside each other in a synchronised cine display using a linear grey scale (table 4):

- i. to check that the heart is in the field of view throughout the acquisition
- ii. to look for sources of artefact including patient motion, upward creep, attenuation by soft tissue and external objects, hot activity adjacent to the heart that might obscure myocardial activity or cause reconstruction artefact, and low count artefact<sup>54</sup>
- iii. to look for evidence of left ventricular dilatation (either permanent or transient) or right ventricular hypertrophy and/or dilatation

- iv. to check whether there is increased lung uptake of tracer particularly thallium-201 (>50% of maximum myocardial uptake),<sup>55</sup> or significant tracer uptake outside the heart or tissue radiopharmaceutical
- v. to assess the pattern of myocardial uptake, although this is more clearly seen in the tomograms

### **8.3 Review of tomograms**

#### **8.3.1 Tomogram display**

- i. Reconstructed tomograms should be viewed on a computer screen for reporting. Reporting from film or paper reproductions should be avoided.
- ii. The three tomographic planes should be displayed: vertical long axis, horizontal long axis and short axis.
- iii. A continuous colour scale should be used because it provides the best inter-observer agreement.<sup>56</sup>
- iv. For ECG-gated and ungated studies, if automatic edge detection is used, the computer-derived edges should be inspected to ensure that they have been correctly defined. Incorrectly defined endocardial and epicardial borders will lead to wrong volume and ejection fraction calculations, and to incorrect polar displays and quantification.<sup>50</sup>

#### **8.3.2 Left ventricular size and right ventricular uptake and size**

- i. Assessment of the tomographic images should begin with a qualitative assessment of the left ventricular cavity size in both sets of images. Dilatation that is worse in the stress images than at rest usually indicates ischaemia-induced dilatation.<sup>55</sup> This is seen less commonly with technetium-99m tracers because of the delayed imaging. Care should be taken that areas of reduced uptake in the stress images do not simulate dilatation.
- ii. Tracer uptake in the right ventricle should also be noted. Significant right ventricular tracer uptake (>50% of maximum left ventricular uptake) indicates right ventricular hypertrophy, and the right ventricle may also be dilated.<sup>57</sup>

#### **8.3.3 Perfusion defect localisation, extent and severity**

- i. Tracer uptake should be evaluated visually in all areas of the left ventricular myocardium. Segmental analysis can be performed using a number of models of the left ventricular myocardium, and a 17 segment model is recommended by several American Societies.<sup>58</sup>
- ii. Tracer uptake can be classified semi-quantitatively as normal (100-70% maximal uptake), mildly reduced (69-50% maximal uptake), moderately reduced (49-30% maximal uptake), severely reduced (29-10% maximal uptake), and absent (9-0% maximal uptake). These figures are approximate and allowance should be made for normal variation and for artefact. Thus, the inferior wall may be judged to have normal uptake at much lower values if attenuation artefact is considered to be present.<sup>59</sup>

#### 8.3.4 Review of ECG-gated tomograms

- i. The beat-length histogram, if available, and the time-volume curve should be inspected to ensure that gating was appropriate. Cine inspection of the gated tomograms may also give clues of inadequate gating, such as inappropriate positioning of diastole or reduced counts in some frames.
- ii. The computer-derived endocardial and epicardial edges should be checked to ensure that they have been appropriately selected.
- iii. Wall motion is best evaluated in linear grey scale without computer-derived edges, and can be classified as normal, hypokinetic, akinetic or dyskinetic (paradoxical).<sup>60</sup> Computer generated contours can be helpful but these should not be used as the sole determinant of motion.
- iv. Wall thickening is best evaluated in a continuous colour scale without computer-derived edges, and is related to the increase in counts between diastole and systole. Computer generated contours can be helpful but these should not be used as the sole determinant of thickening. Thickening can be classified as normal, reduced or absent.<sup>60</sup>
- v. Left ventricular end-diastolic volume, end-systolic volume, stroke volume and ejection fraction may be calculated automatically, although the values obtained should be checked against initial qualitative assessment. Caution should be exercised in reporting apparently spurious values of these parameters. For instance, volumes are often too low and ejection fraction too high in small ventricles.<sup>50</sup>

#### 8.4 Quantification

For routine clinical reporting, formal quantitative analysis may not be necessary. However, it can be helpful to supplement semi-quantitative visual analysis with quantitative analysis of the polar display, particularly to measure the extent and depth of abnormalities.<sup>61</sup> The patient's polar map is compared with a normal database, which should be gender- and radionuclide-specific and may also be institute-specific.<sup>50</sup> An alternative to the polar display is the display of circumferential count profiles but this is less common. Any form of quantification should be validated in published studies and the methodology used should be fully described and should be understood by those who use the technique. Quantitative results must not be reported in isolation and without expert review of the images from which the results are derived.

#### 8.5 Integration of findings

The tomographic findings should be integrated to reach a final interpretation:

- i. An improvement in tracer uptake from stress to rest ("inducible perfusion abnormality") often indicates the presence of inducible ischaemia.<sup>62</sup> An improvement in tracer uptake of one category indicates mild inducible ischaemia, of two categories indicates moderate inducible ischaemia, and of more than two categories indicates severe inducible ischaemia.
- ii. A reduction in tracer uptake that does not change from stress to rest ("fixed perfusion abnormality") normally indicates myocardial infarction, and the degree of reduction

indicates the transmural extent of infarction from mild partial thickness infarction to full thickness infarction.

- iii. Differentiation between true abnormality of tracer uptake and artefact requires experience. Features in favour of attenuation artefact are visualisation of the attenuating structure in the projection images, the fixed nature of the defect, in an expected site (e.g. inferior wall or anterior wall in women), limited extent, smooth edges, poor correspondence with a coronary territory, or an unexpected finding. None of these features however is universally reliable. Features indicating reconstruction artefact are a limited mild-to-moderate fixed defect at the apex ("apical thinning") or intense liver or gall bladder activity that passes behind the inferior wall in the projection images.<sup>54</sup>
- iv. A deterioration in tracer uptake from stress to rest ("rapid tracer washout" or "reverse redistribution") is often artefactual but it may suggest partial thickness infarction with a patent artery.<sup>63,64</sup>

## **8.6 Reporting**

### **8.6.1 Patient details**

The patient's personal details (name, age, gender and address) should be included at the start of the report. Any hospital/clinic identification number and source of referral should also be included (table 5).

### **8.6.2 Type of study**

The imaging protocol should be specified, including the radiopharmaceutical used, imaging technique, sequence and date of study.

### **8.6.3 Indication(s) for study**

The clinical indication(s) for the study should be stated, including relevant clinical history. This supports justification of the study, summarises clinical information that may have been gleaned from a number of sources and focuses the final conclusion.

### **8.6.4 Stress technique**

The stress technique used should be described briefly, including any symptoms, haemodynamic changes and details of ECG changes during or after stress if relevant.

### **8.6.5 Findings**

The appearance of the stress, rest and gated images should be described succinctly, including a statement on overall study quality if appropriate. Recommended practice is to report the defect(s) in the stress tomograms in decreasing order of severity, and then to state how each defect changes in the rest tomograms in the same order. At this stage tracer uptake is being described. Clinical deductions such as the state of myocardial viability and perfusion can be reserved for the conclusion (see below).

### **8.6.6 Conclusion**

- i. The findings should be integrated to reach a final interpretation.<sup>59</sup> Specifically, the report should comment on the presence (if any) of inducible perfusion abnormality, infarction and significant artefact. If there is an abnormality, its location (in terms

of segments affected), extent (in terms of number of segments affected) and severity should be stated.

- ii. Other abnormalities to mention if present are left ventricular dilatation (persistent or transient), increased lung uptake of tracer, right ventricular tracer uptake suggesting hypertrophy (with or without right ventricular dilatation), and significant non-cardiopulmonary tracer uptake.
- iii. If the study is normal, this should be stated specifically bearing in mind that homogeneous myocardial perfusion during stress does not exclude non-obstructive coronary disease.
- iv. A statement on likelihood of future coronary events should be made if clinically relevant. This is deduced from the presence, extent and depth of inducible perfusion abnormalities, the left ventricular ejection fraction if known, and other markers of prognosis such as transient dilatation and lung uptake. If no inducible perfusion abnormalities are present then the ejection fraction is the main determinant of prognosis. This statement should ideally be made in semi-quantitative terms (e.g. "the likelihood of future coronary events is in the region of 5-10% per year") since qualitative terms ("high", "intermediate", "low" are not uniformly interpreted.
- v. If correlation with coronary anatomy or assessment of myocardial viability or hibernation are relevant, these should be commented on bearing in mind the normal variation of coronary anatomy.
- vi. Finally, it should be ensured that the conclusion answers the clinical question that prompted the referral if possible, and if not it may be relevant to make recommendations for further investigation or management.

## **9 Factors Affecting the Quality of Studies**

### **9.1 Stress technique**

- i. Inadequate stress reduces the sensitivity for detecting coronary artery disease (table 6).<sup>22,65</sup>

### **9.2 Tracer dosage and delivery**

- i. Inadequate delivery of radiopharmaceutical degrades image quality and may decrease the diagnostic accuracy of the technique. This may occur if the wrong dose of tracer for patient weight/size is administered or if the injection is not intravenous.
- ii. Inappropriately timed tracer delivery (i.e. not coinciding with peak stress) may reduce the sensitivity of the technique.

### **9.3 Image reconstruction and processing**

- i. Inappropriate filtering during tomographic reconstruction may degrade image quality.
- ii. Inappropriate use of colour or grey-scale windows may lead to diagnostic inaccuracies.
- iii. For quantitative analysis of regional myocardial and lung activity, care should be taken that regions of interest do not include activity from adjacent structures.<sup>66</sup>



Table 1. Pharmacological stress protocols

Agent	Protocol	Radiotracer injection time
<b>Vasodilators</b>		
Dipyridamole	0.56 mg/kg IV over 4 min	4 min after completion of infusion
Adenosine	140 µg/kg/min for 6 min	within 3-4 min of infusion
<b>Inotropic agents</b>		
Dobutamine	Starting at 5-10 µg/kg/min and increasing by 5-10 µg/kg/min every 3-5 min up to 40 µg/kg/min	Peak stress (≥85% MPHR*) and/or maximal dose (40µg/kg/min)

\* MPHR = age- and gender-maximal predicted heart rate

Table 2. Percentages of reported side effects during pharmacological stress.<sup>31,32,33,67,68</sup> AV = atroventricular, SVT = supraventricular tachycardia.

Side Effects	Dipyridamole n = 3911	Adenosine n = 9256	Dobutamine n = 144
Chest Pain	20	35	31
Dyspnoea	3	35	14
Flushing	3	37	14
Headache	12	14	14
Palpitation	3	1	29
Dizziness	12	9	-
Hypotension	5	2	15
High degree AV block	2	5	0
SVT/ventricular arrhythmias	5	3	4
Bronchospasm	0.15	0.1	0

*Table 3. Summary of adverse events reported per 10<sup>4</sup> patients undergoing stress for myocardial perfusion imaging.<sup>3,31,32,33</sup> MI = myocardial infarction.*

	Exercise	Dobutamine	Dipyridamole	Adenosine
Fatal MI / cardiac death	1	0	0.95	0
Non-fatal MI / major cardiac complication	5	0	1.76	1.1

*Table 4. Sources of artefact apparent on cine review of projection images*

- patient motion – cranio-caudal and lateral
- upward creep
- attenuation by soft tissue (diaphragm and breast)
- external objects
- high activity adjacent to the heart
- low count density

*Table 5. Summary of recommendations for reporting*

Sections	Key points
Patient details	Name, age, gender and hospital identification number
Type of study	Imaging protocol, including radiopharmaceutical and date of study
Indication(s) for study	Clinical indication(s) and relevant data from medical history
Stress technique	Agent, dose and protocol, haemodynamic response, ECG changes, symptoms and adverse events
Findings	Description of stress, rest and gated images Description of significant artefact if present
Conclusion	Interpretation of myocardial perfusion (e.g. inducible perfusion abnormality, myocardial infarction) and functional information Correlation with clinical information and other data if available

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Prognosis/risk assessment if clinically relevant

Interpretation of myocardial viability or hibernation if clinically relevant

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*Table 6. Factors affecting the quality of studies*

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<b>Phase of study</b>	<b>Factor</b>
Stress	Incorrect agent or protocol
	Submaximal stress or presence of antagonists
Radiopharmaceutical administration	Inadequate dose for body mass index
	Misadministration (e.g. extravascular injection)
Image acquisition	Inadequate camera positioning or orbit selection
	Inappropriate energy window selection or collimation
	Patient comfort and motion
	External attenuating objects or inadequate breast strapping
	Incorrect ECG-gating
Image reconstruction and processing	Inappropriate filtering or reconstruction technique
	Definition of long axis of left ventricle
Image display	Inappropriate colour scale or incorrect windowing
	Comparison of non-equivalent tomograms

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### **List of Abbreviations**

AF	atrial fibrillation
ARSAC	Administration of Radioactive Substances Advisory Committee
BP	blood pressure
DBP	diastolic blood pressure
ECG	electrocardiogram
LBBB	left bundle branch block
LPO	left posterior oblique

RAO	right anterior oblique
RBBB	right bundle branch block
SBP	systolic blood pressure
SPECT	single photon emission computed tomography
SVT	supraventricular tachycardia
VF	ventricular fibrillation
VPB	ventricular premature beat
VT	ventricular tachycardia

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