

Procedure Guidelines for Radionuclide Myocardial Perfusion Imaging

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

**Writing Group: C Anagnostopoulos, M Harbinson, A Kelion, K Kundley,
CY Loong, A Notghi, E Reyes, W Tindale, SR Underwood**

**Advisory Group: A van Aswegen, AJW Hilson, M Metcalfe, T Nunan, M
Prescott, EM Prvulovich, AC Tweddel, G Vivian**

Address for Correspondence:

Constantinos Anagnostopoulos MD, PhD, FESC

Consultant & Honorary Senior Lecturer

Royal Brompton Hospital

Sydney St, London SW3 6NP

Tel: +44 (20) 7351 8666

Fax: +44 (20) 7351 8668

Email: c.anagnostopoulos@rbh.nthames.nhs.uk

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1 Background

Radionuclide myocardial perfusion imaging uses an intravenously administered radiopharmaceutical 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, global and regional myocardial function.

Radionuclide myocardial perfusion imaging is an established and non-invasive imaging technique with diagnostic and prognostic efficacy in the investigation of Coronary Artery Disease. It is the only widely available method of assessing myocardial perfusion directly but there are differences in the way it is performed in various national and international centres.

Harmonisation of practice, at least at a national level, is therefore essential and clinical governance now makes it mandatory for practice to be based upon evidence whenever possible.[1]

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 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.

2 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 the three societies.

A systematic literature search of Pub Med/MEDLINE [2] 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,[3][4] ACC / AHA / ACP-ASIM guidelines for the management of patients with chronic stable angina,[5] American Society of Nuclear Cardiology imaging guidelines for nuclear cardiology procedures,[6] Society of Nuclear Medicine procedure guideline for myocardial perfusion imaging 2.0).[7] 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.

3 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 disease:

- 3.2.1 to determine the likelihood of future coronary events, for instance after myocardial infarction or related to proposed non-cardiac surgery [8][9][10]
- 3.2.2 to guide strategies of myocardial revascularisation by determining the haemodynamic significance of coronary lesions [11]
- 3.2.3 to assess the adequacy of percutaneous and surgical revascularisation [12]
- 3.3 To assess myocardial viability and hibernation, particularly with reference to planned myocardial revascularisation [13]
- 3.4 Special indications:
 - 3.4.1 to assess the haemodynamic significance of known or suspected anomalous coronary arteries and muscle bridging [14][15]
 - 3.4.2 to assess the haemodynamic significance of coronary aneurysms in Kawasaki's disease [16][17]

4 Stressing the Myocardial Perfusion System

4.1 DYNAMIC EXERCISE

4.1.1 *Indication*

Dynamic exercise is the stress technique of choice in the assessment of patients with suspected or known coronary artery disease provided that the patient is able to exercise to an acceptable workload (e.g. at least 85% of the maximum predicted heart rate). 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 rate-limiting calcium channel antagonists should be discontinued for five half-lives before the test unless medically contraindicated.
- ii. Patients should also avoid caffeine-containing foods, beverages and medications for a minimum of 12 hours prior to the test. This policy allows the use of vasodilator agents (dipyridamole, adenosine) in case the exercise is terminated and pharmacological stress is undertaken (see section 4.2 below).
- iii. Patients should be instructed to dress appropriately for exercise.
- iv. 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 assistance with an urgency appropriate to the situation as defined in local or national guidelines. [18]
- ii. The healthcare professional supervising the stress test should be current in immediate life support (ILS) provided that there is rapid access to personnel trained in ALS and that appropriate assistance and emergency support is available.

- iii. Initial evaluation should include medical history (including symptoms, coronary risk factors, medication and prior diagnostic and therapeutic procedures) and review of referral letters and other medical records if available. Physical examination may also be required, particularly if contraindications to dynamic exercise such as left ventricular outflow obstruction are suspected.
- iv. Justification and authorization for performing the test should be confirmed before starting in compliance with current legislation.
- 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 workload in each level until an end point is achieved, and a recovery period. The preferred method is the Bruce protocol.[19] 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.[3]
- 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 required for the detection of ST segment and T wave changes and 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 at least 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 one to 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 >20 mmHg below baseline or of more than 20% from a previous stage despite an increase in workload, if this is considered to be related to myocardial ischaemia
- 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, 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 that it is not possible to monitor the adequacy of stress and it is not equivalent to physiological stress experienced by the patient in everyday life.

Pharmacological stress with vasodilators is the procedure of choice for patients unable to exercise adequately [20][21] and for those with LBBB or paced rhythm.[22][23]

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 and preferably for 24 hours.[24][25] Aminophylline and theophylline must be stopped 24 hours before the test.[26] 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.[27] 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 the adenosine infusion. However, the tracer injection should be given over 10 to 20 seconds to avoid a sudden bolus of adenosine. The adenosine is infused at 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.[28] 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 after three to four minutes of infusion or sooner if symptoms or other complications 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.[29] Intravenous aminophylline (75-250 mg) may be required to reverse these effects although its half-life is shorter than that of dipyridamole (tables 2 and 3).[30][31][32][33][34]

- v. *Dobutamine stress.* Dobutamine infusion is commonly used when dynamic exercise 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.[32][35] 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 $\geq 85\%$ of the age- and gender-maximal predicted heart rate is reached or at 40 µg/kg/minute, although stress may be adequate at lower heart rates. The dobutamine infusion should be continued for one minute after injection of thallium-201 or one to two minutes after injection of technetium-99m labelled tracers and is then stopped. 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.[36][37] Dobutamine infusion should be discontinued for the same reasons as exercise testing (see paragraph 4.1.4).

4.3 PRECAUTIONS

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

4.4 CONTRAINDICATIONS

4.4.1 *Absolute Contraindications to Dynamic Exercise*

- i. non-ST-segment elevation acute coronary syndrome Once stabilised, exercise stress can be considered 24 to 72 hours after chest pain depending upon clinically assessed risk.[38] [39]
- ii. ST-segment elevation myocardial infarction within the previous 4 days [40]
- iii. left main coronary artery stenosis that is likely to be haemodynamically significant*
- 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*

[*reference 3]

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[22][23]
- ii. inability or poor motivation to perform dynamic exercise

- iii. recent exercise ECG with inadequate exercise

These are not strictly contraindications to dynamic exercise but they can compromise the accuracy of the test.

4.4.3 *Absolute Contraindications to Vasodilator stress*

- i. Recent acute coronary syndrome. Once stabilised, stress with vasodilators can be considered 24 to 72 hours after chest pain depending upon clinically assessed risk [38][39][40]
- ii. suspected or known severe bronchospasm†
- iii. second and third degree atrioventricular block in the absence of a functioning pacemaker†
- iv. sick sinus syndrome in the absence of a functioning pacemaker†
- v. hypotension (SBP <90 mmHg)†
- vi. xanthines intake in the last 12 hours, or dipyridamole use in the last 24 hours†

[†reference 6]

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 [6]
- ii. Recent cerebral ischaemia or infarction

4.4.5 *Absolute Contraindications to Dobutamine Stress*

- i. as for dynamic exercise above
- ii. known hypokalaemia [41]

4.4.6 *Relative Contraindications to Dobutamine Stress*

- i. LBBB, bifascicular block, and paced rhythm, 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 *Administrated activity*

The diagnostic reference level is 80 MBq for stress and redistribution imaging. An additional injection of 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.[42][43] Such reinjection activities are not normally approved as a routine by the United Kingdom Department of Health's Administration of Radioactive Substances Advisory Committee (ARSAC) [44] and must be given at the discretion of the practitioner in individual cases. A higher activity 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 10-20 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 activity 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 (400 - 800µg) can be administered at least 5 minutes beforehand in order to reduce resting hypoperfusion and to detect more accurately myocardial viability. Other nitrates such as buccal isosorbide dinitrate may also be used and these 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.[45]
- 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 3-4 hours after the stress injection.
- 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.[46] 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 *Administrated activity*

The diagnostic reference level 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.[44] Higher activities 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.[47][48]

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). The two-day protocol is ideal from the imaging point of view but it may be less convenient for the patient. The one-day protocols are acceptable alternatives.
- 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 is given in some centres 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.[49][50]

6 Image Acquisition

Image acquisition should be performed using a gamma camera that meets accepted standards of quality control.[51]

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 [52] but it can produce anterior artefacts and it is not recommended in isolation.

- ii. Female patients should be imaged without underclothes. A chest band can be used to minimise breast attenuation and to ensure reproducible positioning during later image acquisition. This can however increase attenuation depending upon how the band is applied and careful attention to technique is required when the breasts are strapped.[53] 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 an 180° rotation from RAO 45° to LPO 45°. With a dual-headed camera the heads should ideally be at 90° to each other for an 180° rotation. A circular or non-circular orbit can be used according to preference.[54]
- ii. Low-energy general purpose collimation should be used for thallium-201 and high-resolution collimation for technetium-99m tracers.[7]
- iii. A 15%- 20% energy window at 72 and 167 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.[6] A zoomed acquisition can be used depending upon camera dimensions but this should be done carefully so 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, activity of radiopharmaceutical and patient size. Typically, for a 90° dual-headed camera acquiring 64 images (32 projections for each detector), 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 rest acquisition. Total acquisition times of longer than 20-30 minutes can be counterproductive as they increase the likelihood of patient motion.[6]

- vi. ECG-gating can be performed, particularly with technetium-99m-labeled radiopharmaceuticals. Sixteen frames per cardiac cycle should be acquired for accurate calculation of left ventricular ejection fraction.[55][56]
- 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.[7]
- 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.[7]

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 as per the manufacturer's recommendations e.g. of 0.5 cycles per centimetre (order 5 or 10) and 0.75 cycles per centimetre respectively can be 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.[6]
- 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 planar projection images and 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 tomographic acquisition should be displayed with the top of the colour scale at the maximum within the myocardium for each set. Displays with the top of the colour scale at the maximum of each individual 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 bottom end of the colour scale should be set to zero and background subtraction should be avoided. Neighbouring pairs of tomograms can be summed for display according to local preference.[57]

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,[58] each method behaves differently and none overcomes artefacts entirely, some even introducing new forms of artefact from overcorrection.[59] The effectiveness of these techniques in routine clinical practice is currently uncertain.[60] They should 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 exercise time, symptoms, haemodynamic observations and ECG changes. 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 PLANAR PROJECTION DATA

Before interpreting the tomograms, the stress and rest planar 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 [61]
- 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), [62] significant tracer uptake outside the heart or extravasated radiopharmaceutical at the site of venepuncture.

- v. to assess the pattern of myocardial uptake, although this is seen more clearly 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.[63]
- 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.[55]

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 indicates ischaemia-induced dilatation.[62] 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.[64]

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.[65]
- 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.[66]

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).[67] 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.[67]
- 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.[55]

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.[68] The patient's polar map is compared with a normal database, which should be gender- and radionuclide-specific and may also be institute-specific.[55] 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 relative tracer uptake from stress to rest ("inducible perfusion abnormality") often indicates the presence of inducible ischaemia.[69] 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 especially if moving normally on ECG-gated images, an expected site (e.g. inferior wall or anterior wall in women), of 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.[61]
- 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.[70][71]

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. Common 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.[66] 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 assessment of myocardial viability/hibernation is relevant, or correlation with coronary anatomy is required, 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).[20] [72]

9.2 TRACER ACTIVITY 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 activity of tracer for patient weight/size is administered or if the injection is inadequately flushed or extravasated.
- 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.[73]

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
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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