

Procedure Guidelines for Radionuclide Myocardial Perfusion Imaging with Single-Photon Emission Computed Tomography (SPECT)

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

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1. Background

This document is an update of the 2004 procedure guidelines for myocardial perfusion scintigraphy. Some of the previous recommendations have been updated or replaced by evidence-based statements and new sections have been added.

Myocardial perfusion scintigraphy (MPS) uses an intravenously administered radiopharmaceutical to image myocardial viability and 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.

Clinical governance makes it mandatory for practice to be based upon evidence whenever possible. 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. Only brief comment is made on other nuclear techniques for assessing myocardial perfusion such as positron emission tomography (PET).

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. New references and supporting evidence were included and data summarised by each guideline developer with discrepancies reconciled by consensus. All recommendations are based on either evidence from clinical studies, previous published guidelines or expert consensus of the writing and advisory groups.

3. Indications for Myocardial Perfusion Scintigraphy

- To assess the presence, site and degree of coronary obstruction in patients with suspected coronary artery disease
- To aid the management of patients with known coronary heart disease:
 - to determine the likelihood of future coronary events, for instance after an acute coronary syndrome (ACS) or related to proposed non-cardiac surgery [1 2]
 - to guide strategies of myocardial revascularisation by determining the haemodynamic significance of coronary lesions [3]
 - to assess the adequacy of percutaneous and surgical revascularisation[4]
- To assess myocardial viability and hibernation, particularly with reference to planned myocardial revascularisation[5]
- Special indications are:
 - to assess the haemodynamic significance of known or suspected anomalous coronary arteries and muscle bridging[6 7]
 - to assess the haemodynamic significance of coronary aneurysms in Kawasaki's disease[8 9]
 - to assess risk in asymptomatic patients with chronic kidney disease[10]

- to assess the presence and extent of obstructive coronary artery disease in patients with arrhythmia. Although a common request, there are little data to support this indication.

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. In particular, dynamic exercise is the ideal form of stress for patients with suspected or known anomalous coronary arteries, muscle bridging or microvascular disease. Exercise should be avoided in patients with left bundle branch block (LBBB) or paced rhythm on their resting ECG as it may result in perfusion abnormalities in the absence of coronary artery stenosis.[11]

4.1.2 Patient Preparation

- Withdrawal of medications that may interfere with the physiological response to exercise should be considered. In general, for the performance of diagnostic studies, beta-blockers should be withdrawn for 48 hours or for the equivalent of five half-lives prior to the test unless medically contraindicated. The continuation of these agents may lead to underestimation of the extent of inducible perfusion abnormality.[12] Other anti-anginal medication, in particular calcium channel antagonists and nitrates, may be withheld for 24-48 hours prior to the stress test.
- Patients should also abstain from caffeine containing foods and from methylxanthine containing drugs (aminophylline, theophylline) for a minimum of 24 hours prior to the test.

This practice allows the use of vasodilator agents in cases where the exercise is terminated and pharmacological stress is undertaken (see section 4.2 below).

- Patients should be instructed to dress appropriately for exercise.
- Some authorities recommend that patients should fast for a minimum of 2 hours prior to the test. The advantage of this however is unproven.

4.1.3 Protocol

- Exercise testing must be led by a suitably trained healthcare professional. In the absence of a national position statement for appropriate training, 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 with urgency appropriate to the situation as defined in local or national guidelines.[13 14]
- The healthcare professional supervising the stress 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.
- Patients should be given an explanation of the purpose and conduct of the test, including information on potential side effects and complications. Consent is obtained verbally in most centres.
- Initial evaluation should include medical history (including symptoms, cardiovascular risk factors, medication and prior diagnostic and therapeutic procedures) and review of referral letter 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.
- Justification and authorization for performing the test should be confirmed before starting in accordance with the Ionising Radiation (Medical Exposure) Regulations 2000[15] and any local procedures that ensure compliance.

- 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 an end point is achieved, and a recovery period. The preferred method is the Bruce protocol.[16]
Bicycle ergometer protocols generally involve an initial low workload of 25 watts, followed by increases of 25 watts every 2 or 3 minutes until end points are achieved.[17]
- 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.
- 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.
- 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 two minutes after technetium-99m perfusion tracer injection.

Exercise testing should be stopped if there is:

- ST segment elevation >0.1 mV in leads without Q waves

- 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
- serious arrhythmias (e.g. VF, VT, frequent and symptomatic VPBs, multifocal VPBs, AF, SVT, second or third degree atrioventricular block and symptomatic bradycardia)
- severe angina
- physical signs of peripheral hypoperfusion such as cyanosis or pallor
- 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 associated with severe symptoms.

4.2 Pharmacological stress

4.2.1 Indication

Pharmacological stress is an 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 [18 19] and for those with LBBB or paced rhythm.[11]

4.2.2 Patient Preparation

Some authorities recommend that patients should fast for a minimum of 2 hours prior to stress testing. The advantage of this however is unproven.

Vasodilator stress

Patients stressed with the vasodilators adenosine, regadenoson or dipyridamole must avoid consumption of any products containing methylxanthines including caffeinated foods and drinks (coffee, tea, chocolate), caffeine-containing medications, aminophylline and theophylline for a minimum of 24 hours prior to the test.[20 21] Caffeine ingestion may attenuate the normal vasodilator response to adenosine,[22]dipyridamole[23] and regadenoson.[24] Attenuation of adenosine-induced perfusion abnormality by caffeine can be overcome by increasing the adenosine dose (see section 4.3 below). Dipyridamole should be withheld for at least 24 hours prior to adenosine or 48 hours before Regadenoson administration. If feasible, beta blocker medication should be withdrawn 48 hours, or for the equivalent of five half-lives, prior to the test. The continuation of beta-blockers may lead to underestimation of the extent and depth of inducible perfusion abnormality.[25] Other antianginal medication, in particular calcium channel antagonists and nitrates should be discontinued prior to the test if possible (see section 4.1.2). A detailed explanation of the procedure should be given, outlining possible side effects and complications. Consent is obtained verbally in most centres.

Dobutamine stress

Patients should stop beta-blockers for 48 hours, or for the equivalent of five half-lives, prior to the test. The continuation of beta-blockers may lead to underestimation of the magnitude of inducible perfusion abnormality.[26] A detailed explanation of the procedure should be given, outlining possible side effects and complications. Consent is obtained verbally in most centres.

4.2.3 Protocol

The stress must be led by a suitably trained healthcare professional as for dynamic exercise (see paragraph 4.1.3). Initial evaluation of the patient's medical history, examination if appropriate, and justification and authorization for performing the test are mandatory.

Adenosine

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 mcg/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.[27] If this is the case a bicycle ergometer may be 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 tracer is injected between the third and fourth minutes of the adenosine 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. In patients with well-controlled or mild asthma or chronic obstructive pulmonary disease (COPD), adenosine can be given as a titrated protocol starting at a low dose of 70 or 100 mcg/kg/min for a minute and increasing if tolerated up to 140 mcg/kg/min with tracer injection two minutes after the maximal dose of 140 mcg/kg/min. Patients who are already on a beta-2 adrenergic agonist such as salbutamol can be given two puffs of the inhaler prior to starting the adenosine infusion.[28 29]

Regadenoson

Regadenoson is administered as a single dose of 400 mcg in 5 ml. No adjustment for patient weight, renal or hepatic function is needed. Regadenoson is given intravenously as a 10-second injection followed immediately by a 10-ml saline flush with tracer injection 10 to 20 seconds after the saline injection. Regadenoson can be combined with submaximal exercise when tolerated. Regadenoson has also been used during dynamic exercise when maximal exercise is not achieved but there is little evidence for the effectiveness and safety of this approach.[30] Heart

rate, blood pressure and ECG should be recorded at baseline and every 2 minutes until stress-induced haemodynamic changes are improving and the patient regains baseline status.

Symptoms during the test should be recorded. Regadenoson is well-tolerated and most side effects are mild and short-lasting but some symptoms may last up to 30 minutes.[31 32]

Aminophylline (50 to 250 mg) may be administered as a low intravenous injection of 50-100 mg over 30-60 seconds to counteract persistent or intolerable symptoms. Patients with moderate to severe COPD as well as patients with mild to moderate asthma tolerate regadenoson well and hence this agent is not contraindicated in patients with obstructive airway disease but it should be administered with caution.[33 34]

Dipyridamole

Intravenous dipyridamole is infused at a rate of 140 mcg/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 until stress-induced haemodynamic changes are improving and the patient regains baseline status. 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.[35 36] Intravenous aminophylline (75-250 mg) may be required to reverse these although its half-life is shorter than that of dipyridamole (tables 2 and 3).[35 37]

Dobutamine

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 mcg/kg/minute up to a maximum of 40 mcg/kg/minute.[38 39] 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 1 minute into the highest dobutamine dose. 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. Additional atropine at doses of 0.3 -0.6 mg up to 1-2 mg may be given to patients who do not achieve target heart rate with dobutamine infusion alone. 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

The following are generally considered to be absolute contraindications to exercise stress, though under some circumstances exercise may be clinically appropriate under experienced medical supervision:

- ST-segment elevation myocardial infarction within the previous 4 days
- 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.[40]
- left main coronary artery stenosis that is likely to be haemodynamically significant
- left ventricular failure with symptoms at rest

- recent history of life-threatening arrhythmias
- severe symptomatic dynamic or fixed left ventricular outflow tract obstruction (aortic stenosis and obstructive hypertrophic cardiomyopathy)
- severe or malignant systemic hypertension
- recent pulmonary embolism or infarction
- thrombophlebitis or active deep vein thrombosis
- active endocarditis, myocarditis or pericarditis

4.4.2 Relative contraindications to dynamic exercise

These are not strictly contraindications to dynamic exercise but they can compromise the specificity of the test:

- left bundle branch block (LBBB) and ventricular paced rhythms, because dynamic exercise leads to perfusion abnormalities of the septum and adjacent walls in the absence of obstructive coronary disease
- inability or poor motivation to perform dynamic exercise
- recent exercise ECG with inadequate exercise

4.4.3 Absolute contraindications to vasodilator stress

- Unstable acute coronary syndrome. Adenosine stress can be performed early (24-48 hours) after an uncomplicated acute infarction
- suspected or known severe bronchospasm, although regadenoson can be used in selected patients
- second and third degree atrioventricular block in the absence of a functioning pacemaker
- sick sinus syndrome in the absence of a functioning pacemaker
- hypotension (SBP <90 mmHg)

- xanthines (caffeine, aminophylline or theophylline) intake in the last 24 hours. Adenosine dose can be increased up a maximum of 210 mcg/kg/min if tolerated in patients who have consumed caffeine within 12 hours prior to the test.[41]

4.4.4 Relative contraindications to vasodilator stress

- bradycardia of less than 40 beats per minute. Initial dynamic exercise normally increases the rate sufficiently to start the infusion.
- dipyridamole medication taken in the last 24 hours. Initial low dose adenosine infusion with subsequent increase if tolerated is used in some centres but there is no published evidence to support this practice. Anecdotal experience suggests that IV dipyridamole can be administered safely in these circumstances but there is no evidence to support this practice.
- Recent cerebral ischaemia or infarction

4.4.5 Absolute contraindications to dobutamine stress

- as for dynamic exercise above
- known hypokalaemia [42]

4.4.6 Relative contraindications to dobutamine stress

- LBBB and paced rhythm for the same reason as for dynamic exercise

5. Radiopharmaceuticals

For SPECT imaging, thallium-201 and two technetium-99m labelled radiopharmaceuticals (sestamibi and tetrofosmin) are available commercially. For PET imaging, positron emitting radiopharmaceuticals Oxygen-15 water and Nitrogen-11 ammonia are also used, but because of their short half-life require an on-site cyclotron. Myocardial perfusion PET using Rubidium-82

has been shown to provide advantages in terms of more accurate attenuation correction and improved diagnostic accuracy, but is not widely available as yet.

It is important to check regarding pregnancy and breast feeding. For women of child bearing age national guidelines should be followed.[43] Pregnant women in general should not undergo tests which results in high radiation exposure to the foetus due to a small increase in risk of cancer. However the exposure from most of the current diagnostic procedures is less than 1 milligray and the additional risk of cancer is 1 in 10,000 compared to a natural risk of 1 in 500.[43] It is preferable to perform imaging in women of childbearing age, if clinically appropriate, within the first 10 days of menstrual cycle.[43] Breast feeding has been noted to cause intense breast uptake of thallium 201, Tc-99m sestamibi and Tc-99m tetrofosmin leading to uninterpretable studies.[43] The duration of increased uptake following cessation of breast-feeding is unknown. For this reason it is recommended that myocardial perfusion studies should not be performed during breast feeding or for several months post cessation.[44]

5.1 Thallium-201

Thallium-201 is initially distributed after intravenous injection to the myocardium according to myocardial viability and perfusion. Because it is a potassium analogue, thallium-201 uptake reflects myocardial blood flow more accurately than any of the other SPECT tracers. It redistributes from this distribution over several hours, thus allowing redistribution images to be acquired that are independent of perfusion and reflect viability alone. However its physical characteristics of low energy (80KeV) and relatively long half-life (73hrs) lead to low count images and increased attenuation artefacts as compared with technetium radiopharmaceuticals and higher radiation dose. Gated images are possible, but the low count statistics may be a cause for concern. For these reasons thallium has mainly been superseded by technetium radiopharmaceuticals except for viability studies.

5.1.1 Allowable activity

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.[45 46] 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)[47] 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

- 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.
- 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 increase the correspondence of the resting images with 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

- 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.
- Stress imaging should begin within 5 minutes of stress injection and should be completed within 30 minutes of injection.
- Redistribution imaging should be performed 3-4 hours after the stress injection.
- 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.[48] This protocol is normally sufficient for the assessment of myocardial viability.
- Imaging can also be performed 24 hours after injection using a longer acquisition time for the assessment of myocardial viability.

5.2 Technetium-99m sestamibi 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 the better count statistics permits ECG-gating, which gives additional functional information. The radiation dose to the patient is considerably less than for thallium-201. 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 Allowable activity

The maximum usual dose for tomography is a total of 1600 MBq for a one-day stress/rest protocol (divided as 400 MBq and 1200 MBq), or 800 MBq on each day of a two-day protocol.[47] Two-day protocols are recommended on the grounds of superior image quality but these may not be practicable. If a one-day protocol is performed, a count density of 1:3 or 4 between the two studies is recommended. Higher doses can be considered on an individual basis by the practitioner, for instance in obese patients. Administered activity may be increased on a graded basis either based on body weight or body mass index with an aim to achieve a constant count density (counts/pixel) independent of body habitus. This should be implemented only following specific approval from ARSAC.[47]

5.2.2 Administration

- 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.
- 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.[49 50]

5.2.3 Imaging Protocols

- 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 recommended on the grounds of image quality, but it may be less convenient for the patient. The one-day protocols are acceptable

alternatives provided that it is recognised that residual activity from the first injection contaminates the second image.

- If a one-day protocol is performed, a rest-first study has advantages including better contrast between normal and ischaemic segments and lesser time interval between the two studies. However, in patients with low pre-test likelihood of obstructive coronary disease, one might wish to consider a stress- first study, especially with ECG gating and attenuation correction to obviate the need for a rest study.
- 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.
- 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.[51 52] A fizzy drink or a water-based beverage immediately before imaging may also reduce interference from gut activity.[53]

6. Image Acquisition

Image acquisition should be performed using a gamma camera that meets accepted standards of quality control (QC).[54 55] For SPECT/CT systems quality control of the CT component is also important. Daily QC of the CT must include the manufacturer prescribed x-ray tube warm-up procedure and automatic monitoring (usually at various tube voltage and current settings) of the x-ray tube output and detector response. Additional evaluation of tomographic uniformity, CT number values (Hounsfield units) and image noise should be performed daily to weekly (modern scanners may include this as part of their required daily CT QC).[56]

There have been advances in gamma camera technology recently, including solid state technology, innovative collimator designs, and the incorporation of resolution recovery software. The combination of these features can offer greatly improved detector sensitivity together with improved spatial and energy resolution over that of conventional gamma cameras. Solid state dedicated cardiac cameras are already commercially available. This technology is rapidly evolving so there are as yet no recommendations for quality assurance of these systems or for the imaging protocols to be used with them. Centres using these systems must ensure suitable quality assurance tests are devised and that imaging protocols have been validated with phantoms before use.

6.1 Patient positioning

For conventional gamma cameras the patient is usually supine with one or both arms above the head and supported in a comfortable position. It is desirable that the left arm should lie outside the imaging arc of the camera. Patient comfort is essential to minimise motion. A knee support may be useful to minimize back discomfort. It is essential that patient positioning is reproducible between stress and rest imaging. Prone imaging has been used in some centres to reduce the incidence of inferior attenuation artefact[57] but it can produce anterior artefacts and it is not recommended in isolation.

Female patients should be imaged without underclothes. A chest band may 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. Chest bands can also be used in males to reduce motion.

6.2 Acquisition parameters

These recommendations apply to conventional gamma cameras and are not applicable to newer technologies such as those mentioned above, for which the manufacturer's recommendations should be followed.

- Dual head tomographic imaging is commonly performed over a 180° rotation from RAO 45° to LPO 45°. A circular or non-circular orbit can be used according to preference.
- Low-energy general purpose collimation should be used for thallium-201. If resolution recovery software is available the use of low energy general purpose collimation for technetium-99m tracers should also be considered in order to reduce either the acquisition time or the administered dose. For gamma cameras without availability of resolution recovery software high-resolution collimation should be used for technetium-99m tracers.[58]
- A 15%- 20% energy window at 72 and 167 keV for thallium-201 and 140 keV for technetium-99m-labeled radiopharmaceuticals should be selected.
- The acquired pixel size should be in the region of 6mm.[59] 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.
- 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 equipment, protocol, dose of radiopharmaceutical, patient size and reconstruction algorithm. Total acquisition times of longer than 20-30 minutes can be counterproductive as they increase the likelihood of patient motion.[59]
- ECG-gating should be performed, particularly with technetium-99m-labeled radiopharmaceuticals. Eight frames per cardiac cycle is commonly used, but sixteen frames per cardiac cycle provides more accurate measurement of left ventricular ejection fraction or parameters of diastolic function.[60]

- The decision whether to perform ECG gating in patients with significant variation in R-R interval (arrhythmias) should be made on an individual patient basis. Newer gamma cameras with '9th bin' capability allow gated data acquisition with a narrow window (e.g. 20%) even in the presence of arrhythmias without compromising the static perfusion data. If this facility is not available, then using a widest possible R-R interval is recommended. When acquiring gated data with a wide window, frequency of ectopic beats should be monitored and if there is more than 1 ectopic per 6 normal beats, the gated acquisition should be abandoned.
- 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.[58]
- The planar projection images should be reviewed immediately after acquisition to check for unacceptable motion, low count density, interference from high gut activity or other source of artefact such as foreign objects or motion of the heart outside the field of view in some projections.[58]

7. Attenuation Correction: Methods and Acquisition

Non-homogeneous photon attenuation is a cause of artefact limiting diagnostic accuracy. A number of techniques have been developed for correcting for attenuation. Many of these incorporate additional corrections for scatter and for depth-dependent resolution recovery. Attenuation correction provides a modest increase in diagnostic accuracy.[61 62] However care should be taken with their use as new forms of artefact can be introduced by overcorrection or by mis-registration between the CT images and the reconstructed slices. Attenuation correction of SPECT images may be performed either using a radionuclide line source (e.g.gadolinium-153) or more commonly now by using a CT detector integrated into the gamma camera gantry.

However it may itself introduce artefacts of its own. Misalignment between emission and transmission data can risk incomplete correction and create artificial perfusion defects. Mis-registration of just 1 pixel can cause a diagnostically significant artefact.

The registration between emission and transmission images must be assessed carefully and registration correction performed when necessary. Attenuation correction should be incorporated with scatter correction in an iterative reconstruction and should not be applied alone. There is evidence that when applied correctly attenuation correction can increase diagnostic accuracy.[63]

8. Image Processing

8.1 Reconstruction

Resolution recovery software is now available from many manufacturers. It can be used to achieve comparable or better image quality with lower count density than standard iterative techniques. Parameters need to be optimised to suit local preferences and equipment. Its use is encouraged if available.

- When resolution recovery software is not available iterative reconstruction should be used rather than filtered background projection if attenuation correction has been performed and it can also be used without attenuation correction.
- When neither resolution recovery nor iterative reconstruction is available filtered back projection using Butterworth and Hanning filters is still an acceptable method of reconstruction. Cut-off frequencies should be chosen according to the manufacturer's recommendations. 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.[59]

8.2 Reorientation

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.

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).

8.3 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; significant motion may not be appropriately corrected by motion correction software and hence images should be re-acquired whenever possible;
- inaccurate ECG-gating; gated parameters should not be reported if this is the case and if severe enough and there is no provision of an 'extra bin', a non-gated study should be re-acquired;
- interference from high gut activity close to the heart; this may cause artefactual reduction in counts in adjacent regions of the myocardium or may obscure a real perfusion abnormality; image re-acquisition should be considered if severe;

- 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.

For attenuation corrected images the registration of the reconstructed slices with the CT images should be checked and the images re-registered or repeated if mis-registration is severe.

8.4 Image display

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.

The use of a continuous colour scale is recommended when reviewing tomograms, as it provides semi-quantitative information on count distribution throughout the myocardium, and it also improves image interpretation for non-experts.[64] 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.

8.5 Attenuation correction: Interpretation

Corrected images should not be used without review alongside the uncorrected images. The reader should familiarise themselves with the changes in image appearance caused by attenuation correction such as reduced apical counts or increased inferior counts.

Newer SPECT/CT AC systems are becoming ubiquitous. While most departments use low dose/resolution CT for attenuation correction, if the CT component is considered to be of diagnostic quality, it is good clinical practice to review the CT images obtained for abnormalities. There should be a local policy for the reporting of the low dose CT images obtained for AC. When non-cardiac abnormalities are identified, this should be communicated to the referring clinician with an appropriate recommendation for further investigation. This may require joint reporting sessions with CT accredited physicians.

9 Image Interpretation

9.1 Review of clinical details

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.

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.

9.2 Review of projection 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):

- to check that the heart is in the field of view throughout the acquisition
- 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[65]
- to look for evidence of left ventricular dilatation (either permanent or transient) or right ventricular hypertrophy and/or dilatation
- to check whether there is increased lung uptake of tracer particularly thallium-201 (>50% of maximum myocardial uptake),[66]significant tracer uptake outside the heart or extravasated radiopharmaceutical at the site of venepuncture.
- to assess the pattern of myocardial uptake, although this is more clearly seen in the tomograms

9.3 Review of tomograms

9.3.1 Tomogram display

- Reconstructed tomograms should be viewed on a computer screen for reporting. Reporting from film or paper reproductions should be avoided.
- The three tomographic planes should be displayed: vertical long axis, horizontal long axis and short axis.

- A continuous colour scale should be used because it provides the best inter-observer agreement.[64]
- 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.

9.3.2 Left Ventricular Size and Right Ventricular Uptake and Size

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 may indicate ischaemia-induced dilatation.[66] 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. 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.[67]

9.3.3 Perfusion Defect Localisation, Extent and Severity

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.[68] 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.[69]

9.3.4 Review of ECG-gated Tomograms

- 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.
- The computer-derived endocardial and epicardial edges should be checked to ensure that they have been appropriately selected.
- Wall motion is best evaluated in linear grey scale without computer-derived edges, and can be classified as normal, hypokinetic, akinetic or dyskinetic (paradoxical).[69]
- Computer generated contours can be helpful but these should not be used as the sole determinant of motion.
- 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.[69]
- 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.[60]

9.4 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.[70] The patient's polar map is compared with a normal database, which should be gender- and radionuclide-specific and may also be institute-specific. 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.

9.5 Integration of findings

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

- An improvement in relative tracer uptake from stress to rest ("inducible perfusion abnormality") often indicates the presence of inducible ischaemia. 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.[69]
- 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. However, when reporting partial-thickness infarction it should be borne in mind that the relationship between counts and transmural extent of infarction is not linear because of partial volume effect in thinned myocardium.
- 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.[65]

- 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.[71 72]

9.6 Reporting

9.6.1 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).

9.6.2 Type of study

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

9.6.3 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.

9.6.4 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.

9.6.5 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).

9.6.6 Conclusion

- The findings should be integrated to reach a final interpretation. 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. Non-cardiac abnormalities, especially those derived from CT based AC systems should be interpreted.
- Other abnormalities to mention if present are 1) ischaemic ECG changes, hypotension (SBP<90mmHg) or blunted heart rate response during exercise or pharmacological stress, especially in the absence of perfusion abnormality. Such responses are associated with significant multivessel or left main stem disease and poor prognosis;[73 74] 2) left ventricular dilatation (persistent or transient); 3) increased lung uptake of tracer;4) right ventricular tracer uptake suggesting hypertrophy (with or without right ventricular dilatation); and 5) significant non-cardiopulmonary tracer uptake.

- 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.
- 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 may 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.[75]
- If correlation with coronary anatomy or assessment of myocardial viability or hibernation is relevant, these should be commented on bearing in mind the normal variation of coronary anatomy.
- 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.

10. Factors Affecting the Quality of Studies

10.1 Stress technique

Inadequate stress reduces the sensitivity for detecting coronary artery disease (table 6).[18]

10.2 Tracer dosage and delivery

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 inadequately flushed or extravasated. Inappropriately timed tracer delivery (i.e. not coinciding with peak stress) may reduce the sensitivity of the technique.

10.3 Image reconstruction and processing

Inappropriate filtering during tomographic reconstruction may degrade image quality, while inappropriate use of colour or grey-scale windows may lead to diagnostic inaccuracies. For quantitative analysis of regional myocardial and lung activity, care should be taken that regions of interest do not include activity from adjacent structures.[76]

11. Audit and consensus reporting

All aspects of Nuclear Cardiology procedures should be regularly evaluated for quality. For example, there may be opportunity to take part in UK regional audits such as those previously coordinated by IPEM/BNMS. Ongoing audit of reporting within and between sites, and attendance at multidisciplinary meetings, is desirable. This includes compliance with the advice on revalidation on nuclear cardiology as set out by the Royal Colleges and appropriate professional bodies.

Appropriate arrangements for consensus reporting between specialties should be arranged locally when indicated, particularly when cardiac CT data is incorporated in the imaging investigation.

List of Abbreviations

AC	Attenuation correction
AF	atrial fibrillation
ARSAC	Administration of Radioactive Substances Advisory Committee
BP	blood pressure
CT	computed tomography
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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