Revised 2009 (Res. 14)*

ACR–SNM–SPR PRACTICE GUIDELINE FOR THE PERFORMANCE OF CARDIAC SCINTIGRAPHY

PREAMBLE

These guidelines are an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. They are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care. For these reasons and those set forth below, the American College of Radiology cautions against the use of these guidelines in litigation in which the clinical decisions of a practitioner are called into question.

The ultimate judgment regarding the propriety of any specific procedure or course of action must be made by the physician or medical physicist in light of all the circumstances presented. Thus, an approach that differs from the guidelines, standing alone, does not necessarily imply that the approach was below the standard of care. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in the guidelines when, in the reasonable judgment of the practitioner, such course of action is indicated by the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of the guidelines. However, a practitioner who employs an approach substantially different from these guidelines is advised to document in the patient record information sufficient to explain the approach taken.

The practice of medicine involves not only the science, but also the art of dealing with the prevention, diagnosis, alleviation, and treatment of disease. The variety and complexity of human conditions make it impossible to always reach the most appropriate diagnosis or to predict with certainty a particular response to treatment. Therefore, it should be recognized that adherence to these guidelines will not assure an accurate diagnosis or a successful outcome. All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The sole purpose of these guidelines is to assist practitioners in achieving this objective.

I. INTRODUCTION

This guideline was revised collaboratively by the American College of Radiology (ACR), the Society for Pediatric Radiology (SPR), and the Society of Nuclear Medicine (SNM).

It is intended to guide physicians performing cardiac scintigraphy in adults and children**.** Properly performed imaging with radiopharmaceuticals that localize in either the myocardium or the blood pool is a sensitive means of detecting and quantitatively assessing numerous conditions involving the heart. As with all other scintigraphic techniques, maximum diagnostic accuracy is achieved by correlation with clinical findings, imaging with other radiotracers not discussed in this guideline, and other diagnostic tests.

Application of this guideline should be in accordance with the ACR Technical Standard for Diagnostic Procedures Using Radiopharmaceuticals, with particular attention paid to the prescription and handling of radio-pharmaceuticals.

II. GOAL

The goal of cardiac scintigraphy is to evaluate myocardial perfusion and/or function to detect physiologic and anatomic abnormalities of the heart and determine prognosis.

III. INDICATIONS AND CONTRAINDICATIONS

Five major classes of cardiac scintigraphy are included in this guideline: myocardial perfusion imaging (single-photon-emission computed tomography [SPECT] or planar, stress and/or resting, gated or ungated), gated cardiac blood-pool imaging (resting and/or stress), first-pass cardiac imaging, myocardial infarction imaging, and shunt evaluation. Indications for these studies include, but are not limited to, the following:

A. Myocardial Perfusion Imaging

1. Detecting the presence, location, and extent of coronary artery disease.
2. Evaluating the physiologic significance or sequelae of coronary artery stenosis.
3. Monitoring the effects of treatment of coronary artery disease, including revascularization and medical therapy.
4. Detecting acute myocardial infarction.
5. Evaluating the viability of dysfunctional myocardium.
6. Stratifying risk of myocardial events.
7. Evaluating ventricular function (using gated images).
8. Determining prognosis after myocardial infarction.
9. Preoperative stratification of risk for adverse cardiovascular events during noncardiac surgery.

B. Gated Cardiac Blood-Pool Imaging

1. Quantifying parameters of ventricular function (e.g., ejection fraction, wall motion, ventricular volume, cardiac output, diastolic function).
2. Detecting the presence, location, and extent of coronary artery disease.
3. Assessing whether congestive heart failure is due to ischemic or nonischemic causes.
4. Evaluating and monitoring potential cardiotoxic effects of cancer chemotherapy.
5. Evaluating the effects of valvular abnormalities.

C. First-Pass Cardiac Imaging

1. Calculating left and right ventricular ejection fractions.
2. Assessing wall motion abnormalities.
3. Quantifying left-to-right cardiac shunts.
4. Measuring cardiac output and absolute ventricular chamber volumes.

D. Myocardial Infarction Imaging

Diagnosing and assessing the location and extent of acutely infarcted myocardium.

E. Right-to-Left Shunt Evaluation

Detecting and quantifying right-to-left shunts using radiolabeled particles.

For the pregnant or potentially pregnant patient, see the ACR Practice Guideline for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation.

IV. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Technical Standard for Diagnostic Procedures Using Radiopharmaceuticals.

V. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for cardiac scintigraphy should provide sufficient information to demonstrate the medical necessity of the examination and allow for its proper performance and interpretation.

Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). Additional information regarding the specific reason for the examination or a provisional diagnosis would be helpful and may at times be needed to allow for the proper performance and interpretation of the examination.

The request for the examination must be originated by a physician or other appropriately licensed health care provider. The accompanying clinical information should be provided by a physician or other appropriately licensed health care provider familiar with the patient's clinical problem or question and consistent with the state's scope of practice requirements. (ACR Resolution 35, adopted in 2006)

A. Myocardial Perfusion Imaging

1. Radiopharmaceutical
   a. Thallium-201 (thallous chloride)
      Thallium is injected intravenously in administered activity of 2.0 to 4.0 millicuries (74 to 148 MBq). When stress is used, injection should precede cessation of stress by 1 minute. Thallium-201 is recommended when the purpose of the study

is to assess myocardial viability because it redistributes. Imaging is routinely started within 10 minutes after injection. Redistribution images are obtained 3 to 4 hours after injection, with or without the additional reinjection of 1.0 millicurie (37 MBq) of thallium. If reinjection of 1.0 mCi of thallium is planned prior to redistribution imaging, the dose used for stress imaging may be limited to 3 mCi. When assessing myocardial viability, additional information may be gained by obtaining 24-hour delayed images. Other sequences, such as rest and delayed redistribution imaging, may also give useful information about myocardial viability.

b. Technetium-99m sestamibi
Sestamibi is taken up by the myocardium according to regional myocardial perfusion. Unlike thallium, very little redistribution occurs. Measurement of regional myocardial perfusion during stress and rest requires 2 separate intravenous injections. Imaging is usually begun 15 to 120 minutes after administration of the radiopharmaceutical. Numerous imaging protocols have been described (e.g., rest-stress 1 day, stress-rest 2 days, and resting thallium-stress sestamibi or dual isotope technique). The protocol chosen should reflect the needs of the patient and the logistics of the institution. One-day total administered activity of up to 40 millicuries (1,480 MBq) of sestamibi may be used. The stress injection should be given 1 to 2 minutes prior to cessation of exercise. Gated perfusion SPECT imaging can be performed.

c. Technetium-99m tetrofosmin
Tetrofosmin is taken up by the myocardium according to regional myocardial blood flow. Procedures are the same as those described for technetium-99m sestamibi in section V.A.1.b above. One-day total administered activity of up to 40 millicuries (1,480 MBq) may be used.

2. Patients
Patients should be evaluated prior to the study for their ability to undergo physical or pharmacologic stress safely. Patients who are unable to exercise may be stressed pharmacologically. If a patient is unable to tolerate physical stress for cardiac reasons, pharmacologic stress may also be contraindicated. All patients undergoing stress should have intravenous access and should wear comfortable clothing and shoes. External attenuating objects should be removed, if possible. Patients should fast for at least 4 hours prior to exercise or pharmacologic stress. They may have sugar-free beverages prior to the redistribution phase of a thallium study but otherwise should remain NPO and not exercise more than is absolutely necessary.

3. Stress
Stress may be performed by physical or pharmacologic means. A brief summary of the level and method of stress should be included in the imaging report.

a. Physical
For patients who are physically able to exercise, the desired endpoint is a heart rate of at least 85% of the age-predicted maximum predicted heart rate (MPHR) or a workload of at least 5 mets. The patient must be monitored frequently for abnormal change in blood pressure, marked systolic time (ST) changes on the electrocardiogram, development of serious arrhythmias, severe chest pain, or other signs or symptoms of myocardial ischemia. With development of angina, stress may be discontinued and the reason so noted. If exercise is terminated prior to the achievement of 85% of the age predicted maximum heart rate due to noncardiac limitations such as musculoskeletal, neurological, or pulmonary symptoms, abnormalities associated with coronary stenosis may be underestimated or missed. Beta-blocking and calcium-channel-blocking medications often prevent the patient from achieving the desired heart rate and may reduce the sensitivity of the test. Depending on the clinical necessity or the clinical question, these agents may need to be discontinued by the patient's physician prior to examination for a time sufficient to obviate their pharmacologic effect.

b. Pharmacologic
The heart may be stressed using one of a variety of pharmaceutical agents (e.g., dipyridamole, adenosine, or dobutamine). Depending on the clinical necessity or the clinical question, beta-blocking and calcium-channel-blocking agents may need to be discontinued by the patient's physician prior to examination for a time sufficient to obviate their pharmacologic effect.

i. Dipyridamole is infused intravenously in a dose of 0.14 mg/kg/min for 4 minutes (total dosage = 0.56 mg/kg). Its duration of action is between 30 minutes and 1 hour. The radio-

pharmaceutical should be injected 2 to 4 minutes after the end of the dipyridamole infusion. Dipyridamole has numerous side effects, including chest pain, headache, dizziness, hypotension, nausea, flushing, and dyspnea. Severe reactions have included fatal and nonfatal myocardial infarctions and severe bronchospasm. Aminophylline (1 to 2 mg/kg) must be immediately available for intravenous injection and should be given to reverse significant side effects. Because all xanthines (e.g., caffeine and theophylline) interfere with the pharmacologic effect of dipyridamole, they must be discontinued for 24 to 48 hours prior to the examination. Patients who have unstable angina, bronchospastic airway disease, and second-degree heart block are at increased risk for complications of dipyridamole administration, and these conditions should be considered relative contraindications to use of the drug. As with physical stress, clinical, blood pressure, and electrocardiographic monitoring are mandatory during the dipyridamole infusion and for a period of time following the infusion.

ii. Adenosine may also be given intravenously in a dose of 0.14 mg/kg/min over 6 minutes (3 minutes prior to injection of the radiopharmaceutical and continued for 3 minutes thereafter). Shorter infusion protocols (4 to 5 minutes) have been used successfully with adenosine. While using shorter infusion protocols, the radiotracer should be injected at least 2 to 2.5 minutes prior to termination of adenosine infusion. Because of the extremely short duration of the pharmacologic action of adenosine, injection of the radiopharmaceutical must occur during the adenosine infusion. Side effects are similar to those of dipyridamole but are very short lived, often eliminating the need for aminophylline. Adenosine is vulnerable to the same interference from xanthine-containing foods, beverages, and medications as is dipyridamole, so all must be discontinued for 24 to 48 hours prior to examination. Hemodynamic, electrocardiographic, and clinical monitoring must be carried out the same as with any other form of stress.

An A2A adenosine receptor agonist for use as a pharmacologic stress agent in radionuclide myocardial perfusion imaging (MPI) is now commercially available. The agent (regadenoson) is administered as a rapid intravenous injection (approximately 10 seconds) with no dose adjustment required for body weight. It should not be administered to patients with second-degree or third-degree AV block or sinus node dysfunction who do not have a functioning artificial pacemaker.

iii. Both dipyridamole and adenosine can be combined with simultaneous low-level exercise in patients who are ambulatory, to reduce the side effects of these agents, reduce subdiaphragmatic radiotracer uptake, and improve image quality. While using dipyridamole, exercise should start after the completion of dipyridamole infusion and should last 4 to 6 minutes. While using adenosine, exercise should be simultaneous with the adenosine infusion. Low-level exercise such as the first 2 stages of the modified Bruce Protocol suffices. Its duration of effect is short (biologic half-life of approximately 2 minutes).

iv. Dobutamine is infused intravenously. A number of protocols are available. One involves the graduated infusion of increasing amounts of dobutamine over time, beginning with 5 to 10 mcg/kg/min over 3-minute increments, rising by 5 to 10 mcg/kg/min each step, with a maximum dose rate of 40 mcg/kg/min. Atropine may be needed to achieve target heart rate. The endpoint is 85% of MPHR or side effects similar to those listed in sections V.3.a. and V.3.b.i. Beta-blockers and calcium-channel blockers must be withdrawn far enough in advance of the test to eliminate their effect. Dobutamine stress is an alternative in patients who have obstructive pulmonary disease. Dobutamine is associated with an increased incidence of cardiac arrhythmia and should be given with extreme caution in patients prone to arrhythmias or in the post-myocardial infarction period.

4. Safety

When exercise or pharmacologic stress is performed or hemodynamically unstable patients

are studied, life support instruments, medications, and appropriately trained personnel (advanced cardiac life support [ACLS] or pediatric advanced life support [PALS]) must be available in the immediate vicinity of the stress laboratory. Baseline blood pressure measurement and electrocardiographic tracing should be obtained before performing either a stress test using exercise or a pharmacologic stimulation. Electrocardiographic and blood pressure monitoring must be performed during stress and recovery.

5. Imaging

   For most applications, SPECT should be performed. Planar imaging may be performed when the patient is unable to undergo SPECT (e.g., extreme obesity, claustrophobia, or inability to lie recumbent or remain immobile).

   a. SPECT

      The patient may be placed supine on the imaging table and should be instructed to stay as motionless as possible. Care should be taken to provide for his/her comfort. It is possible to image with the patient prone, especially in those patients with suspected inferior wall attenuation defects, but this may introduce anterior wall artifacts. The left arm (both arms for some multihead systems) should be raised above the head to reduce attenuation, permit a smaller radius of rotation, and prevent inadvertent contact with the detector. Strapping the arm over the head in rare instances can result in nerve or dialysis shunt injury. Patients should wear similar, loose-fitting clothing for both the immediate and delayed images. To avoid inconsistent attenuation artifacts in a woman, special care should be taken to position the woman's breasts as identically as possible between the stress and resting views.

      The imaging and reconstruction protocol should be chosen for optimum quality and should be used consistently from patient to patient.

      Patient motion and attenuation artifacts may create defects on the reconstructed tomographic filtered image. Cinematic raw data (projection files) should be reviewed to evaluate the study for overall quality, patient motion and attenuation artifacts during image acquisition. Attenuation correction is available on some commercial SPECT systems, and both the attenuation-corrected and the non-attenuation-corrected images should be reviewed when available. Other useful quality control images are the sinogram and summed projection images. Improper reconstruction techniques can also produce artifacts.

      With the high count rates achievable with technetium-99m-based radiopharmaceuticals gated acquisition of images should be carried out routinely. Gated images can be used to calculate ejection fraction and stroke volume and to assess regional wall thickening and wall motion.

      New technology instrumentation such as solid state detectors or wide beam reconstruction techniques may allow more rapid acquisitions or lower administered doses than described elsewhere in this document. In these cases manufacturers' suggested protocols should be followed.

   b. Planar

      At a minimum, images should be obtained in the anterior, shallow left anterior oblique, and left lateral and/or steep left anterior oblique (LAO) projections. When stress and rest/redistribution images are obtained, each pair of images should be as closely matched in positioning as possible.

6. Quantification

   A number of strategies are available for quantitative analysis of planar and SPECT myocardial perfusion studies. Quantitative analysis requires comparison with a normal database. Whether the database is commercially supplied or developed from one's own experience, the interpreting physician is responsible for ensuring the quality of the database. Quantitative analysis only supplements a very careful visual analysis of the raw images and reconstructed images.

B. Gated Cardiac Blood-Pool Imaging (Radionuclide Angiocardiography or Ventriculography)

   1. Radiopharmaceutical

      Technetium-99m-labeled autologous red blood cells, labeled by the in-vivo, in- vivo/in-vitro, or in-vitro technique, are most commonly used. The adult administered activity is usually 15 to 25 millicuries (555 to 925 MBq) administered intravenously, and the examination may commence immediately thereafter. Administered activity for children should be determined based

on body weight and should be as low as reasonably achievable for diagnostic image quality. If a patient has received a recent blood transfusion, is in renal failure, or is on heparin or adriamycin, the in vivo technique may result in unacceptably high levels of unbound technetium-99m. Other medications may have similar effects.

2. Patient
   Except for those patients undergoing stress-gated ventriculography, few restrictions apply. Patients requiring exercise should be evaluated for their ability to undergo the physical stress safely.

3. Stress
   Exercise, when performed, usually consists of graded levels of work performed on a bicycle ergometer with simultaneous acquisition of gated images. These are commonly obtained for 2 to 3 minutes during each level of exercise by imaging after heart rate equilibration, which usually occurs in 1 to 2 minutes. The endpoint may be achievement of a desired predefined work level or percentage of MPHR, anginal symptoms, significant ST segment depression or other electrocardiogram abnormality, or physical inability to continue.

4. Safety
   When hemodynamically unstable patients are studied or when exercise is performed, life support instruments, medications, and appropriately trained personnel (ACLS or PALS) must be available in the immediate vicinity of the stress laboratory. Baseline blood pressure measurement and electrocardiographic tracing should be obtained before performing either a stress test using exercise or ~~a~~ pharmacologic stress. Electrocardiographic and blood pressure monitoring must be performed during stress and recovery.

5. Imaging
   a. Resting
      At least 16 frames per R-R interval are needed for accurate measurement of ejection fraction. The electrocardiographic tracing on the monitor should be inspected before imaging starts to be certain that the R wave is properly triggering acquisition. The angle for the left anterior oblique (LAO) view should be chosen to obtain the best separation of the right and left ventricles. The anterior view should be obtained at an angle that is 45 degrees shallower than the LAO (best septal) view. The left lateral view should be obtained at an angle that is 45 degrees steeper than the LAO view. A left posterior oblique (LPO) view may be substituted for, or can be obtained in addition to, the left lateral view. Caudal angulation (up to 30 degrees if using a slant-hole collimator) may help to separate the ventricular blood pool from the atrial blood pool. The matrix size should be 64 x 64. Each set of images should be acquired for at least 5 minutes or 300,000 counts per frame, whichever occurs first. Recent advances in hardware and software allow SPECT acquisition of gated blood pool images. SPECT acquisition allows a more detailed evaluation of left and right ventricular regional wall motion and calculation of both right and left ventricular ejection fractions.
   b. Stress
      Patients should exercise at each new level of exercise for 1 to 2 minutes to achieve a stable heart rate. Once a stable heart rate is obtained, 2 to 3 minute studies are acquired using the best septal view and approximately 16 frames per cardiac cycle. One study should be acquired at the maximum level of exercise. Studies at other levels of exercise can also be obtained.

6. Quantification
   a. R wave histogram
      Inspection of the R wave histogram provides information on the regularity of cardiac rhythm during the acquisition. Because the gated study averages hundreds of heartbeats, wall motion evaluation and ejection fraction calculations are optimal with a regular rhythm. Fewer than 10% of beats rejected is optimal. If more than 30% of beats are rejected, quantitative results may be unreliable.
   b. Wall motion
      Wall motion can be assessed quantitatively or qualitatively. Functional images such as stroke volume, paradox, regional ejection fraction, amplitude, and phase images may be helpful.
   c. Left ventricular ejection fraction
      All computer programs calculate an ejection fraction using the difference between background-corrected end-diastolic counts and background-corrected end-systolic counts divided by background-corrected end-diastolic counts. The background region of interest should avoid the stomach or the spleen, which can result in erroneously low or high ejection fractions, respectively. Manual, semiautomatic, or fully automatic algorithms for calculating ejection fractions

are available. In addition to the R wave histogram, regions of interest and the ejection fraction curve should be inspected to be certain the quantitative results are consistent with the acquired data. The user of these programs should have a quality control program in place to maximize the precision of the measurement. The user should understand the strengths and limitations of the algorithms used. Computer generated left ventricular ejection fractions should be compared with the visual estimation of ejection fractions to ensure reliability.

C. First-Pass Cardiac Imaging (First-Pass Ventriculography)

1. Radiopharmaceutical
   If the study is performed in conjunction with a gated blood-pool examination, technetium-99m-labeled red blood cells in adult administered activity of 15 to 25 millicuries (555 to 925 MBq) may be used. Other technetium-99m-labeled radiopharmaceuticals (e.g., pertechnetate, diethylene-triamine penta-acetic acid, or sestamibi) may be used if the study is done alone or with another unrelated examination. Administered activity for children should be determined based on body weight and should be as low as reasonably achievable for diagnostic image quality. Injection technique is critically important. Rapid injection of a small volume of the radiotracer into a large proximal vein (e.g., external jugular) or through large-gauge intravenous access in an antecubital vein followed by an instantaneous saline flush is necessary for optimal results, especially when measuring left-to-right shunts. If the bolus is suboptimal, the results may not be valid. Bolus adequacy can be measured by superior vena cava (SVC) bolus analysis.

2. Patient
   No patient preparation is required, unless the procedure is performed as part of an exercise study.

3. Imaging
   Depending on the information desired, the imaging device is positioned over the patient's chest in the anterior or right anterior oblique projection. Data are acquired in list or fast-frame mode for up to 1 minute. A 64 x 64 matrix is preferred. A low-energy all-purpose/general all-purpose (LEAP/GAP) or high-sensitivity collimator is used.

4. Quantification of right and left ventricular ejection fraction(s)
   The user must understand the limitations of the quantitative techniques used to avoid errors. A quality control program should be in place to maximize the value of this test.

5. Evaluation of left-to-right shunt
   The size of cardiac and extracardiac left-to-right shunts also may be measured by assessing first transit pulmonary time-activity curves. The technique is used more commonly in children than adults. The injection technique must ensure delivery of the agent in as tight a bolus as possible. Computer programs, such as gamma variate analysis, are applied to pulmonary curves to determine the pulmonary to systemic blood-flow ratio (QP/QS).

D. Myocardial Infarction (Infarct Avid) Imaging

1. Radiopharmaceutical
   With the availability of serum biomarkers for a rapid diagnosis of acute myocardial infarction, and contrast enhanced magnetic resonance imaging (MRI) for imaging of difficult cases, scintigraphic techniques are rarely used.

   Technetium-99m pyrophosphate, a bone imaging agent, can also be used for imaging acute myocardial infarction. This agent is administered intravenously in activity of 15 to 25 millicuries (555 to 925 MBq).

   Technetium-99 annexin has also been found to be highly effective for imaging acute myocardial infarction. However, this agent is not approved by the FDA for this indication and is currently not available commercially.

   Technetium-99m glucarate is another agent for imaging acute myocardial infarction within 24 hours of the onset. This agent is not approved by the FDA for this indication and is currently undergoing clinical studies.

   The last 2 agents mentioned above are not described any further in this document, and technetium-99m pyrophosphate is described only briefly.

2. Patient
   The maximum sensitivity of technetium-99m pyrophosphate imaging for acute myocardial infarction occurs at 3 to 6 days after the event. Studies obtained as soon as 12 hours after an infarction may be positive**,** but only in a smaller

percentage of cases. Activity in the infarcted area may persist for variable amounts of time in those with large myocardial infarctions.

3. Imaging
   Imaging is conducted 1.5 to 3 hours after radiotracer injection. Patients with poor cardiac output or poor renal function may clear tracer from the blood pool more slowly. Persistent blood pool activity significantly interferes with image interpretation and can result in false positive studies. Delayed imaging may help differentiate infarct from blood pool in patients with persistent blood pool activity. At least three images (anterior, LAO, and left lateral) are acquired For small field of view cameras (≈250 mm) 300,000 to 500,000 counts per image are needed. For large field circular and rectangular detector cameras (400 to 500 mm), 500,000 to 1,000,000 counts should be acquired. SPECT imaging should also be performed. Technetium-99m pyrophosphate is also taken by the normal bones, and tracer uptake in the ribs and sternum and costal cartilages interferes with image interpretation. SPECT imaging is helpful in differentiating skeletal uptake from myocardial uptake.

   Technetium-99m pyrophosphate is also useful for imaging cardiac amyloidosis, a relatively rare disorder. Most of the cardiac Technetium-99m pyrophosphate studies in clinical practice currently are performed to diagnose cardiac amyloidosis. Indium-111-antimyosin imaging has been found to be useful for diagnosing myocarditis, cardiac transplant rejection, and cardiotoxicity of cancer chemotherapy in clinical research studies.

E. Right-to-Left Shunt Detection

Right-to-left shunt detection can be assessed with technetium-99m-labeled macroaggregated albumin (MAA). The usual adult administered activity is 1.0 to 4.0 millicuries (37 to 148 MBq). Administered activity in children should be reduced as stated in section V.C.1. Although no untoward clinical effects related to systemic distribution of MAA have been reported, it may be prudent to limit the number of particles injected, e.g., one-quarter to one-half reduction. Under normal circumstances, this agent will not pass into the systemic circulation. If a right-to-left shunt is present, activity will appear in systemic organs such as the brain, spleen, and kidneys. It is possible to estimate the severity of the shunt by comparing pulmonary counts with systemic counts. This is accomplished by performing a total body image after the intravenous administration of MAA. Imaging should be started within 2 minutes after injecting the radiotracer. The fraction of systemically shunted tracer is determined by dividing systemic counts (i.e., total-body counts minus total-lung counts) by total body counts. The number is converted to a percentage of right-to-left shunt by multiplying by 100. With the availability of cardiac magnetic resonance imaging (flow quantification techniques) and echocardiography, cardiac shunt detection is infrequently carried out with scintigraphic techniques. However, shunt detection may be used in certain chronic disease states that are associated with extracardiac right-to-left shunts.

VI. EQUIPMENT SPECIFICATIONS

A. Myocardial Perfusion Imaging

1. Planar
   For thallium-201, a scintillation camera with a detector head size of 250 to 400 mm and a LEAP collimator may be used. A high-resolution collimator may improve resolution, but longer imaging times will be required to obtain the same number of counts. For thallium-201, imaging is routinely started within 10 minutes after injection. Images should be acquired for 6 to 10 minutes per view. This represents the best compromise between image quality and the need to acquire the images before redistribution occurs. Redistribution images obtained 3 to 4 hours after injection should be acquired for duration of time similar to that for poststress views. Cardiac and respiratory motion reduces the spatial resolution of cardiac studies.

   For technetium-99m sestamibi or tetrofosmin, a high-resolution collimator may be used, and up to 1,000,000 counts per view may be achieved quite easily. Imaging may be started as soon as is convenient after heart rate and respirations slow adequately (to avoid motion artifacts), although a delay of 30 minutes may improve images by allowing some clearance of hepatic activity.

   Currently planar imaging has largely been replaced by SPECT imaging. Planar imaging is only used in cases where SPECT imaging cannot be carried out.

2. SPECT
   SPECT acquisition parameters depend on the radiopharmaceutical and instrument. For single-head cameras, LEAP/GAP collimators and a circular orbit are acceptable. When thallium-201 is used, LEAP/GAP collimators should be used. With sestamibi and tetrofosmin, high-resolution collimators enhance image quality. With dual-isotope imaging, the same collimator should be used for both isotopes. At a minimum, 30 to 32

images in a 180 degree arc from right anterior oblique to LPO should be obtained.

For multihead systems, data can be acquired from either a 180 degree or a 360 degree arc, and images can be reconstructed from the complete circle (ellipse) or the 180 degree arc. Two-head camera systems in which the heads may be positioned at approximately 90 degree angles allow efficient acquisition of data over a 180 degree arc. Smaller imaging intervals (3 degrees rather than 6 degrees) are feasible with triple-head systems and two-head 90 degree systems.

Multihead camera systems are the preferred imaging systems. They decrease image acquisition time compared to single head systems, which helps to improve patient comfort and reduce patient motion.

B. Gated Cardiac Blood-Pool Imaging

A scintillation camera equipped with a LEAP/GAP collimator is required, although a high-resolution collimator provides sharper images on a resting study if the count rate is adequate. An electronic cardiac monitor with an R-wave trigger signal compatible with the camera/computer system used is required. Recently, gated SPECT imaging has been used quite successfully in place of planar imaging for gated blood pool imaging. With the wider availability of appropriate software and computer programs for SPECT blood pool imaging; this is likely to be used increasingly in future.

C. First-Pass Cardiac Imaging

Any standard scintillation camera may be used. However, multicrystal cameras have higher count sensitivity and result in high count statistics compared to standard single crystal gamma cameras. A LEAP/GAP collimator or a high sensitivity collimator is recommended.

D. Myocardial Infarction (Infarct Avid) Imaging

Any scintillation camera may be used. A LEAP/GAP or high-resolution collimator should be used.

E. Right-to-Left Shunt Detection

Any standard scintillation camera may be used. A LEAP/GAP collimator is recommended.

VII. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Guideline for Communication of Diagnostic Imaging Findings.

The report should include the radiopharmaceutical used and the dose and route of administration, as well as any other pharmaceuticals administered, also with dose and route of administration.

VIII. RADIATION SAFETY

Radiologists, medical physicists, imaging technologists, and all supervising physicians have a responsibility to minimize radiation dose to individual patients, to staff, and to society as a whole, while maintaining the necessary diagnostic image quality. This concept is known as "as low as reasonably achievable (ALARA)."

Facilities, in consultation with the radiation safety officer, should have in place and should adhere to policies and procedures for the safe handling and administration of radiopharmaceuticals, in accordance with ALARA, and they must comply with all applicable radiation safety regulations and conditions of licensure imposed by the Nuclear Regulatory Commission (NRC) and by state and/or other regulatory agencies. Quantities of radiopharmaceuticals should be tailored to the individual patient by prescription or protocol.

IX. QUALITY CONTROL AND IMPROVEMENT, SAFETY, INFECTION CONTROL, AND PATIENT EDUCATION

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control, and Patient Education appearing under the heading *Position Statement on QC & Improvement, Safety, Infection Control*, *and Patient Education* on the ACR web page (http://www.acr.org/guidelines).

Equipment performance monitoring should be in accordance with the ACR Technical Standard for Medical Nuclear Physics Performance Monitoring of Gamma Cameras.

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Suggested Reading (Additional articles that are not cited in the document but that the committee recommends for further reading on this topic)

1. Abbott BG, Jain D. Impact of myocardial perfusion imaging on clinical management and the utilization of hospital resources in suspected acute coronary syndromes. *Nucl Med Commun* 2003; 24:1061-1069.
2. Bonow RO. Assessment of myocardial viability. In: Sandler MP, Patton JA, Coleman RE, et al, ed. *Diagnostic Nuclear Medicine*. 3rd ed. Baltimore, Md: Williams & Wilkins; 1996:543-552.
3. DiCarli MF, Gerbaudo VH, Singh TP, et al. Cardiopulmonary studies in pediatric nuclear medicine. In: Sandler MP, Coleman RE, Patton JA, et al, eds. *Diagnostic Nuclear Medicine*. 4th ed. Baltimore, Md: Williams & Wilkins; 2003:1161-1178.
4. Gates GF, Orme HW, Dore EK. Cardiac shunt assessment in children with macroaggregated albumin technetium-99m. *Radiology* 1974; 112:649-653.
5. Iskandrian AS, Verani MS, Heo J. Pharmacologic stress testing: mechanism of action, hemodynamic responses, and results in detection of coronary artery disease. *J Nucl Cardiol* 1994; 1:94-111.
6. Jain D. Technetium-99m labeled myocardial perfusion imaging agents. *Semin Nucl Med* 1999; 29:221-236.
7. Jain D, Zaret BL. Nuclear imaging in cardiovascular medicine. In: Rosendorf C, ed. *Essentials of cardiovascular medicine.* 2nd ed. Totowa, NJ: Humana Press; 2005:221-244.
8. Jain D, Lahiri A, Raftery EB. Immunoscintigraphy for detecting acute myocardial infarction without electrocardiographic changes. *Bmj* 1990; 300:151-153.
9. Jain D, Zaret BL. Antimyosin cardiac imaging: will it play a role in the detection of doxorubicin cardiotoxicity? *J Nucl Med* 1990; 31:1970-1974.
10. Johnson LL. Myocardial hotspot imaging. In: Sandler MP, Coleman RE, Patton JA, et al, eds. *Diagnostic Nuclear Medicine*. 4th ed. Baltimore, Md.: Williams & Wilkins; 2003:333-342.
11. Martin TW, Seaworth JF, Johns JP, Pupa LE, Condos WR. Comparison of adenosine, dipyridamole, and dobutamine in stress echocardiography. *Ann Intern Med* 1992; 116:190-196.
12. Mason JR, Palac RT, Freeman ML, et al. Thallium scintigraphy during dobutamine infusion: nonexercise-dependent screening test for coronary disease. *Am Heart J* 1984; 107:481-485.
13. Murphy PB, Port SC. Radionuclide evaluation of left ventrical function. In: Sandler MP, Coleman RE, Patton JA, et al, eds. *Diagnostic Nuclear Medicine*. 4th ed. Baltimore, Md: Williams & Wilkins; 2003:239-272.

14. Narula J, Acio ER, Narula N, et al. Annexin-V imaging for noninvasive detection of cardiac allograft rejection. *Nat Med* 2001; 7:1347-1352.
15. Nichols KJ, Jain D. Right ventricular parameters: prospect for routine assessment by equilibrium radionuclide angiographic SPECT. *Nucl Med Commun* 2007; 28:155-157.
16. Nusynowitz ML, Benedetto, AR. Cardiac evaluation by nuclear first-pass techniques. In: Guiberteau MJ, ed. *Nuclear Cardiovascular Imaging: Current Clinical Practice*. New York, NY: Churchill Livingstone; 1990:89-100.
17. Panjrath GS, Jain D. Apoptosis for nuclear physicians. *Indian J of Nuc Med* 2004; 19:68-74.
18. Panjrath GS, Jain D. Monitoring chemotherapy-induced cardiotoxicity: role of cardiac nuclear imaging. *J Nucl Cardiol* 2006; 13:415-426.
19. Ritchie JL, Bateman TM, Bonow RO, et al. Guidelines for clinical use of cardiac radionuclide imaging. Report of the American College of Cardiology/American Heart Association Task Force on Assessment of Diagnostic and Therapeutic Cardiovascular Procedures (Committee on Radionuclide Imaging), developed in collaboration with the American Society of Nuclear Cardiology. *J Am Coll Cardiol* 1995; 25:521-547.
20. Strauss HW, Miller DD, Wittry MD, et al. Society of nuclear medicine procedure guideline for myocardial profusion imaging. *Society of Nuclear Medicine Procedure Guidelines Manual 1997*. Reston, Va: Society of Nuclear Medicine; 1997:1-8.
21. Wackers FJ, III. Myocardial perfusion imaging. In: Sandler MP, Coleman, RE, Patton, JA, et al, eds. *Diagnostic Nuclear Medicine*. 4th ed. Baltimore, Md: Williams & Wilkins; 2003:273-318.
22. Wittry MD, Juni, JE, Royal, HD, et al. Society of Nuclear Medicine procedure guideline for gated eqiulibrium radionuclide ventriculography. *Society of Nuclear Medicine Procedure Guidelines Manual 1997*. Reston, Va: Society of Nuclear Medicine; 1997:9-14.

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