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2019 (Resolution 36)*

ACR–NASCI–SNMMI–SPR–STR PRACTICE PARAMETER FOR THE PERFORMANCE OF CARDIAC SCINTIGRAPHY

PREAMBLE

This document is an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. Practice Parameters and Technical Standards are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care¹. For these reasons and those set forth below, the American College of Radiology and our collaborating medical specialty societies caution against the use of these documents 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 practitioner in light of all the circumstances presented. Thus, an approach that differs from the guidance in this document, 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 this document 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 this document. However, a practitioner who employs an approach substantially different from the guidance in this document 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 the guidance in this document 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 this document is to assist practitioners in achieving this objective.

¹ *Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing*, ___ N.W.2d ___ (Iowa 2013) Iowa Supreme Court refuses to find that the *ACR Technical Standard for Management of the Use of Radiation in Fluoroscopic Procedures* (Revised 2008) sets a national standard for who may perform fluoroscopic procedures in light of the standard's stated purpose that ACR standards are educational tools and not intended to establish a legal standard of care. See also, *Stanley v. McCarver*, 63 P.3d 1076 (Ariz. App. 2003) where in a concurring opinion the Court stated that "published standards or guidelines of specialty medical organizations are useful in determining the duty owed or the standard of care applicable in a given situation" even though ACR standards themselves do not establish the standard of care.

I. INTRODUCTION

This practice parameter was revised collaboratively by the American College of Radiology (ACR), the North American Society for Cardiovascular Imaging (NASCI), the Society of Nuclear Medicine and Molecular Imaging (SNMMI), the Society for Pediatric Radiology (SPR), and the Society of Thoracic Radiology (STR).

It is intended to guide physicians performing and interpreting cardiac scintigraphy in adults and children [1,2]. Properly performed imaging with radiopharmaceuticals that localize in either the myocardium or the blood pool is a sensitive means of detecting and quantitatively assessing various conditions involving the heart. As with all other scintigraphic techniques, maximum diagnostic accuracy is achieved by correlation with clinical findings, imaging with other radiopharmaceuticals not discussed in this practice parameter, and other diagnostic tests.

Application of this practice parameter should be in accordance with the [ACR–SPR Technical Standard for Diagnostic Procedures Using Radiopharmaceuticals](#) [3], with particular attention paid to the prescribing and handling of radiopharmaceuticals.

The first part of this practice parameter addresses myocardial perfusion imaging, and the second part covers gated cardiac blood-pool imaging and first-pass cardiac imaging, including left-to-right shunt evaluation.

The primary goals of cardiac scintigraphy are to evaluate myocardial perfusion and/or ventricular function, to detect physiologic and anatomic abnormalities of the heart, and to stratify cardiac risk.

In addition to the performance parameters that follow, as a general rule, significant incidental findings should be identified and reported for both imaging with radiopharmaceuticals and on the CT used for attenuation correction. Because sestamibi localizes in proportion to blood flow and mitochondrial content, angiogenesis/neovascularization seen in neoplasms may result in abnormal uptake and should be reported if seen (ie, breast cancer can be incidentally detected during stress testing). Attenuation correction CT should be reviewed for incidental findings (eg, lung nodules/masses, bulky lymphadenopathy).

PART I MYOCARDIAL PERFUSION IMAGING

II. INDICATIONS AND CONTRAINDICATIONS

Myocardial perfusion imaging encompasses single-photon emission computed tomography (SPECT) or planar techniques, stress and/or rest, gated or ungated. Indications for these examinations include, but are not limited to, the following [4]:

1. Detecting the presence, location, and extent of ischemic coronary artery disease in conjunction with stress testing
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 myocardial infarction
5. Evaluating the viability of dysfunctional myocardium (hibernating myocardium)
6. Stratifying the risk assessment of acute coronary syndromes, including preoperative risk [5]
7. Stratifying the risk after myocardial infarction
8. Evaluating ventricular function and measuring ventricular volumes using gated images

The [ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation](#) provides useful information on radiation risks to the fetus regardless of source. Information on managing pregnant or potentially pregnant patients undergoing nuclear medicine procedures is available from the International Commission on Radiological Protection [6].

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the [ACR–SPR Technical Standard for Diagnostic Procedures Using Radiopharmaceuticals](#) [3].

IV. 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 – revised in 2016, Resolution 12-b)

1. Radiopharmaceutical

a. Technetium-99m sestamibi and Technetium-99m tetrofosmin

Sestamibi and tetrofosmin are taken up by the myocardium proportional to the regional myocardial perfusion. Unlike thallium, very little redistribution occurs. Measurement of regional myocardial perfusion during stress and rest requires two separate intravenous injections. Imaging usually starts 15 to 120 minutes after administration of the radiopharmaceutical. Numerous imaging protocols have been described (eg, 1-day rest/stress, 1-day stress first or stress only, 2-day stress/rest, and rest thallium-stress sestamibi or other dual-radiopharmaceutical techniques). The protocol selection should reflect the needs of the patient and the logistics of the institution. One-day total administered activity of up to 44 mCi (1,630 MBq) of sestamibi or tetrofosmin may be used in most patients. One-day rest/stress protocols typically use a 1:3 ratio for the rest-and-stress injected activities. The stress injection should be given 1 to 2 minutes prior to cessation of exercise. Patients may require larger total administered activity based upon body habitus to obtain diagnostic image quality. In stress/rest protocols, if the stress examination is normal, the rest examination does not need to be performed [7,8]. Routine use of thallium and dual-isotope protocols, such as rest thallium-stress sestamibi, is discouraged because of the higher patient radiation exposure without significant clinical benefits.

b. Thallium-201 (thallous chloride)

Thallium-201 has significantly higher radiation dose than the technetium-99m-labeled radiopharmaceuticals, and it should not be used routinely unless there are specific reasons for its use. Because of its redistribution, thallium-201 can be used when the purpose of the examination is to assess for myocardial viability; however, the use of fluorodeoxyglucose (FDG)- positron emission tomography (PET) or cardiac magnetic resonance imaging (MRI) is preferred. Thallium is injected intravenously in administered activity of 2.0 to 4.0 mCi (74-148 MBq). For an exercise examination, radiopharmaceutical injection should occur 1 minute prior to cessation of stress. 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 mCi (37 MBq) of thallium. If reinjection of 1.0 mCi of thallium is planned prior to redistribution imaging, the administered activity 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 protocols, such as rest and delayed redistribution imaging, may also give useful information about myocardial viability.

c. PET agents (Nitrogen-13 ammonia, or Rubidium-82 chloride)

PET perfusion agents, when equipment and radiopharmaceuticals are available, are preferred imaging agents because of their improved resolution, fast scan times, quantitative myocardial perfusion with flow reserves, and reduced patient radiation exposure compared with technetium-99m perfusion agents.

The studies are generally performed with pharmacologic stress. The stress and rest Rubidium-82 portions of the examination are done in rapid sequence, usually during one positioning on the gantry, whereas for Nitrogen-13 ammonia, a 50-minute period of decay is necessary between the rest and stress portions of the examination. PET/CT allows for routine CT attenuation correction image sets as well as coronary calcium scoring if desired. Studies with Nitrogen-13 ammonia require proximity to a cyclotron because of the short physical half-life. Rubidium-82 chloride studies require a generator system that is available commercially and must be replaced monthly. The very short physical half-life of Rubidium-82 requires that the generator and the delivery system be placed adjacent to the scanner.

2. Patients

Patients should be evaluated prior to the examination 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 examination but otherwise should remain fasting and not exercise more than is absolutely necessary.

3. Stress

For SPECT myocardial perfusion imaging, stress may be performed by physical or pharmacologic means. For PET myocardial perfusion imaging, pharmacologic stress is preferred because of the short physical half-life of the tracers. Exercise is feasible with Nitrogen-13 ammonia but has many practical challenges and may have adverse effects on image quality that are due to patient motion.

A brief summary of the method and level (if exercise or dobutamine) of stress, hemodynamic measurements, electrocardiographic (ECG) findings, and symptoms should be included in the imaging report.

a. Physical

For patients who are physically able to exercise, the desired endpoint is the presence of ischemic symptoms or ECG changes, a heart rate of at least 85% of the age-predicted maximum predicted heart rate (MPHR) or a workload of at least five metabolic equivalents (METs). One hundred percent of MPHR is calculated as 220 minus the patient's age in years; 1 MET = amount of energy expended at rest or 3.5 mL oxygen/kg/min; carrying out activities of daily living requires 5 METs, which is achieved by walking at 1.7 mph (2.7 km/hour) up a 10% incline. The patient must be monitored closely by a physician or other qualified personnel experienced in cardiac stress testing. For further information see the [ACR Nuclear Medicine and PET Accreditation Program Requirements](#). Stress is discontinued before achieving the desired workload if the patient develops angina, specific ECG changes suggestive of ischemia, certain arrhythmias, significant increase or decrease in blood pressure, or signs of hypoperfusion. The reason for premature termination should be recorded. If exercise is terminated prior to the achievement of 85% of the age-predicted MPHR because of 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 examination [9]. Depending on the clinical necessity or the clinical question, these medications may need to be discontinued by the patient's physician prior to examination for a time sufficient to obviate their pharmacologic effect. Contraindications to exercise testing include high-risk acute coronary syndrome, uncontrolled acute cardiac conditions, such as arrhythmias, heart failure, myocarditis, and pericarditis, aortic dissection, severe symptomatic aortic stenosis, and acute medical illness.

b. Pharmacologic

The heart may be stressed using one of a variety of pharmaceutical medications, but a vasodilator stress agent (ie, adenosine, dipyridamole, or regadenoson) is preferred for radionuclide myocardial perfusion imaging unless a contraindication exists, in which case dobutamine should be considered. Depending on the clinical necessity or the clinical question, beta-blocking and calcium channel-blocking medications 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 dosage 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 radiopharmaceutical 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 (1-2 mg/kg) must be immediately available for intravenous injection and should be given to reverse significant side effects. Because all xanthines (eg, 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 or third-degree atrioventricular (AV) block without a functioning pacemaker are at increased risk for complications of dipyridamole administration, and these conditions should be considered at least relative contraindications to use of the medication. As with physical stress, clinical, blood pressure, and ECG 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 dosage 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 (4-5 minutes) have been used successfully with adenosine. While using shorter infusion protocols, the radiopharmaceutical 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. Significant bronchospastic airway disease, second- or third-degree atrioventricular block or sinus node disease without a functioning pacemaker, systolic blood pressure less than 90 mmHg, and recent (less than 48 hours) use of dipyridamole-containing medications are contraindications to adenosine administration. Caution should be used in patients who have had unstable angina and acute coronary syndromes in the last 2 days. Hemodynamic, ECG, and clinical monitoring must be carried out as with any other form of stress.
- iii. Regadenoson is an A_{2A} adenosine receptor agonist administered as a rapid intravenous injection in a dosage of 0.4 mg over 20 seconds; there is no dosage adjustment for body weight/body mass index. Unlike other vasodilator agents, regadenoson can be used in stable bronchospastic airway disease. It should not be administered to patients with a second- or third-degree-atrioventricular block or sinus node dysfunction who do not have a functioning artificial pacemaker. Systolic blood pressure less than 90 mmHg and recent (less than 48 hours) use of dipyridamole-containing medications are contraindications to regadenoson administration. Caution should be used in patients with unstable angina and acute coronary syndromes in the last 2 days and in patients with significant renal impairment.
- iv. All three vasodilator stress agents (adenosine, dipyridamole, and regadenoson) can be combined with simultaneous low-level exercise for SPECT myocardial perfusion imaging in patients who are ambulatory to reduce the side effects of these agents, to decrease subdiaphragmatic radiopharmaceutical uptake, and to 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. Its duration of effect is short (biologic half-life of approximately 2 minutes). Low-level exercise, such as the first two stages of the modified Bruce protocol, suffices. Patients who are ambulatory may also undergo low-level exercise (eg, treadmill at 1.7 mph, 0% grade) for 1.5 minutes followed by regadenoson administration, tracer injection, and an additional 2 minutes of exercise.
- v. 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 µg/kg/min each step, with a maximum dosage rate of 40 µg/kg/min. Atropine may be needed to achieve the target heart rate. The endpoint is 85% of M_{PHR} or side effects similar to those listed in sections IV.3.a. and IV.3.b.i. It is not necessary to withhold beta blockers and calcium channel blockers in advance of the test if the patient is eligible for atropine. Dobutamine stress is an alternative in patients who have

bronchospastic airway disease or certain conduction system disorders. Dobutamine is associated with an increased incidence of cardiac arrhythmia and should be avoided in patients prone to arrhythmias or in the postmyocardial infarction period.

4. Safety

When exercise or pharmacologic stress is performed or when 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 ECG tracing should be obtained before performing either a stress test using exercise or a pharmacologic stimulation. ECG and blood pressure monitoring must be performed during stress and recovery.

5. Imaging

For most applications, SPECT, ~~or~~ SPECT/CT, PET, or PET/CT should be performed [10,11]. Planar imaging may be performed when the patient is unable to undergo SPECT (eg, body habitus, claustrophobia, or inability to lie recumbent or remain immobile).

a. SPECT or SPECT/CT

In most SPECT systems, the patient is placed supine on the imaging table. In some cardiac-specific systems, the patient may sit upright or semi-upright. The patient should be instructed to stay as motionless as possible, and care should be taken to provide for his/her comfort. It is possible to image the patient in the prone position, especially when inferior wall attenuation defects are suspected, but the prone position may also introduce anterior wall artifacts. In one system, two-position supine and semi-upright imaging is performed to resolve possible attenuation artifacts. Depending on the system, either the left arm or both arms should be raised above the head to reduce attenuation, permit a smaller radius of rotation, and prevent inadvertent contact with the detector. In rare instances, strapping the arm over the head can result in nerve or dialysis shunt injury. Patients should wear similar, loose-fitting clothing for both sets of 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 rest images.

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

Patient motion and attenuation artifacts may create defects on the reconstructed tomographic filtered images. Cinematic raw data (projection files), sinograms, and/or linograms, if available, should be reviewed to evaluate the examination for overall quality, patient motion, and attenuation artifacts during image acquisition. Attenuation correction is available on some commercial SPECT or SPECT/CT systems; both the attenuation-corrected and the non-attenuation-corrected images should be reviewed when available [12]. Other useful quality control images are the summed projection images. Improper reconstruction techniques can also produce artifacts [13,14]. When attenuation correction is used, care should be taken to ensure correct alignment of the SPECT and CT data sets.

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 end-diastolic and end-systolic volumes and to assess regional wall thickening and wall motion.

New technology instrumentation, such as solid-state detectors, specialized cardiac collimators, or wide beam reconstruction techniques, may allow for more rapid acquisitions or lower administered activities than described elsewhere in this document [15-18]. In such cases, manufacturers' suggested protocols should be followed [10-12].

b. PET and PET/CT

The patient is placed supine on the imaging table and should be instructed to stay as motionless as possible. Care should be taken to maximize patient comfort. Both arms should be raised above the head to reduce attenuation. Patients should wear loose-fitting comfortable clothing. The imaging and reconstruction protocol should be chosen for optimum quality and should be consistent from patient to patient and between rest and stress images.

Both the attenuation-corrected and the non-attenuation-corrected images should be reviewed when available. When CT attenuation correction is used, care should be taken to ensure correct alignment of the PET and CT data sets.

c. 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. Interpretation

For both SPECT and PET myocardial perfusion imaging, myocardial perfusion images are usually reconstructed and displayed in three standard views (horizontal long axis, vertical long axis, and short axis). Myocardial perfusion is generally graded in a semiquantitative manner using a five-point scale, where 0 = normal uptake, 1 = mildly reduced uptake, 2 = moderately reduced uptake, 3 = severely reduced uptake, and 4 = no uptake. A standard 17-segment myocardial model is commonly used. Global left ventricular systolic function and left ventricular size are generally assessed quantitatively and qualitatively. Regional wall motion is assessed using a combination of visually assessment of thickening and brightening of the segment. Evaluation for coronary artery calcification (for SPECT/CT and PET/CT) and extra cardiac findings are also integral components of the interpretation.

7. Quantification

A number of strategies are available for quantitative analysis of planar, PET, 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 careful visual analysis of the raw and reconstructed images.

Quantification of myocardial blood flow and calculation of myocardial flow reserve with PET is gaining momentum, with the recent addition of a new category III code for PET absolute quantification of myocardial blood flow by the Centers for Medicare and Medicaid Services (CMS in 2018. Although the benefits of PET-based myocardial blood flow and flow reserve are growing, investigations are ongoing in this area for SPECT.

V. EQUIPMENT SPECIFICATIONS

1. Planar

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 clearance of hepatic activity.

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. Thallium-201 chloride redistribution images obtained 3 to 4 hours after injection should be acquired for duration of time similar to that for post-stress views. Cardiac and respiratory motion reduces the spatial resolution of cardiac examinations.

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

2. SPECT

SPECT acquisition parameters depend on the radiopharmaceutical and instrument [10,11]. For single-head cameras, low-energy all-purpose (LEAP)/general all-purpose (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-radiopharmaceutical imaging, the same collimator should be used for both radiopharmaceuticals. At a minimum, 32 images in a 180° arc, from right anterior oblique to left posterior oblique (LPO), should be obtained.

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

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

SPECT/CT cameras have evolved. In addition to attenuation correction, the CT images may allow detection of coronary artery calcification, which may be clinically significant and should be reported [19-21].

The majority of conventional SPECT systems described above are based on Anger camera technology where one or more large-area detectors rotate around the body of the patient. Conventional Anger cameras consist of a single scintillation crystal that absorbs incident gamma rays and scintillates (emits light in response), a bank of photomultiplier tubes and electronics to compute gamma-ray energy and the location of scintillation within the crystal.

More recently, dedicated cardiac SPECT systems that are based on small semiconductor detector modules have been introduced, which directly detect the gamma rays without the use of the scintillation crystal. In these solid-state detectors, gamma rays are absorbed into the semiconductor material, which directly generates electron-hole pairs that are pulled to the end plates through an applied electric field. The collected charge from the electron-hole pairs is used to determine the location and energy of the gamma ray. The small size of these detector modules has made a number of innovative camera designs possible. In one system, multiple pixelated cadmium zinc telluride detector arrays are mounted in vertical columns and placed in gantry over a 90° arc around the patient. Each detector is configured with a high-sensitivity parallel-hole collimator, which restricts its field of view to a small volume. To cover the entire myocardial region, each detector pivots about its own axis, sweeping its field of view across the entire imaging volume. By spending more time imaging the myocardium and less time imaging the rest of the chest, data collection is more efficient and allows reduced scan time or administered tracer activity. During image acquisition, the moving detectors are covered with no visible movement externally, and imaging is performed in a chair to maximize patient comfort, with two-position imaging in the supine and semiupright positions to resolve possible attenuation artifacts.

3. PET

Acquisition can either be in 2-D or 3-D mode. ECG-gated images yield a good-quality ventricular function examination and are acquired in 8 to 16 time frames per R-R interval, in a manner similar to SPECT-gated perfusion studies but at higher spatial resolution. List-mode acquisitions are now available with nearly all cameras, which enable simultaneous dynamic and ECG-gated acquisitions (see [ASNC/SNMMI Position Statement](#) [22]). With PET/CT the reconstructed PET and CT image sets must be accurately aligned for fusion and subsequent attenuation correction.

PART II
GATED BLOOD-POOL IMAGING AND FIRST-PASS CARDIAC IMAGING, INCLUDING LEFT-TO-RIGHT SHUNT EVALUATION

VI. INDICATIONS AND CONTRAINDICATIONS

Cardiac scintigraphy includes gated cardiac blood-pool imaging (rest and/or stress), first-pass cardiac imaging, and left-to-right shunt evaluation. Indications for these examinations include, but are not limited to, the following:

A. Gated Cardiac Blood-Pool Imaging

Quantifying parameters of ventricular function (eg, ejection fraction, wall motion, ventricular volume, cardiac output, diastolic function), including monitoring cardiac effects of chemotherapy

B. First-Pass Cardiac Imaging Including Left-to-Right Shunt Evaluation

1. Calculating left and right ventricular ejection fractions
2. Quantifying left-to-right cardiac shunts

Note: Detecting and quantifying right-to-left shunts using radiolabeled particles are covered in the [ACR–SPR–STR Practice Parameter for the Performance of Pulmonary Scintigraphy](#) [23].

VII. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the [ACR–SPR Technical Standard for Diagnostic Procedures Using Radiopharmaceuticals](#) [3].

VIII. 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 – revised in 2016, Resolution 12-b)

A. Gated/Multigated Acquisition, MUGA Cardiac Blood-Pool Imaging (Radionuclide Angiocardigraphy or Ventriculography)

1. Radiopharmaceutical [24-27]

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 mCi (555-925 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 (ALARA) for diagnostic image quality. For children, the recommended administered activity for a gated blood-pool examination including left-to-right shunt is 5 to 20 mCi (185-740 MBq) [1,2]. If a patient has received a recent blood transfusion, is in renal failure, or is on heparin or doxorubicin, 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 M_{PHR}, 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 ECG tracing should be obtained before performing a stress test using exercise. ECG and blood pressure monitoring must be performed during stress and recovery.
5. **Imaging**
 - a. **Rest**

At least 16 frames per R-R interval are needed for accurate measurement of the ejection fraction. The ECG tracing on the monitor should be inspected before imaging starts to be certain that the R wave is properly triggering the acquisition. The angle for the 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° shallower than the LAO (best septal) view. The left lateral view should be obtained at an angle that is 45° steeper than the LAO view. An LPO view may be substituted for, or can be obtained in addition to, the left lateral view. Caudal angulation (up to 30° 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 × 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 images are acquired using the best septal view and approximately 16 frames per cardiac cycle. One examination 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 (“beat histogram”)**

Inspection of the R-wave histogram provides information on the regularity of the cardiac rhythm during the acquisition. Because the gated examination averages hundreds of heartbeats, wall-motion evaluation and ejection fraction calculations are optimal with a regular rhythm. Less 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, region 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.

B. First-Pass Cardiac Imaging (First-Pass Ventriculography), Including Left-to-Right Shunt Evaluation

1. Radiopharmaceutical [24-27]

If the examination is performed in conjunction with a gated blood-pool examination, technetium-99m-labeled red blood cells in an administered activity of 15 to 25 mCi (555-925 MBq) may be used. Other technetium-99m-labeled radiopharmaceuticals (eg, pertechnetate, diethylene-triamine penta-acetic acid, or sestamibi) may be used if the examination is done alone or with another unrelated examination. Administered activity for children should be determined based on body weight and should be ALARA for diagnostic image quality. For children, the recommended administered activity for first-pass cardiac imaging including left-to-right shunt is 5 to 20 mCi (185-740 MBq). Injection technique is critically important. Rapid injection of a small volume of the radiopharmaceutical into a large proximal vein (eg, external jugular) or through a 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 examination.

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 64×64 matrix is preferred. A 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 examination.

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 in adults. The injection technique must ensure delivery of the radiopharmaceutical 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).

Note: Right-to-Left Shunt Detection: For further information see the [ACR-SPR-STR Practice Parameter for the Performance of Pulmonary Scintigraphy](#) [23].

IX. EQUIPMENT SPECIFICATIONS

A. Gated Cardiac Blood-Pool Imaging

A gamma camera equipped with a LEAP/GAP collimator is required, although a high-resolution collimator provides sharper images on a rest examination 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 the future.

B. First-Pass Cardiac Imaging, Including Left-to-Right Shunt Evaluation

Any standard gamma camera may be used. A LEAP/GAP collimator or a high-sensitivity collimator is recommended.

PART III FDG-PET Viability Imaging

X. INDICATIONS

Evaluation of viable myocardium in cases of suspected stunned or hibernating myocardium.

XI. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the [ACR–SPR Technical Standard for Diagnostic Procedures Using Radiopharmaceuticals](#) [3].

XII. SPECIFICATIONS OF THE EXAMINATION

Two sets of images are required for viability assessment: a perfusion image and an FDG image. Perfusion imaging is first performed with either rubidium-82 chloride or ¹³N-ammonia using procedures described in the PET myocardial perfusion section. If these radionuclides are not available, standard SPECT myocardial perfusion can be performed. The two sets of images are required to assess regional concentrations of FDG relative to regional distribution of myocardial perfusion to differentiate between the various myocardial states. For example, hibernating myocardium is identified by a perfusion-metabolism mismatch (ie, a regional increase in FDG relative to regional perfusion), whereas myocardial scar is identified by a perfusion-metabolism match (ie, a regional reduction in FDG uptake in proportion to regional reductions in myocardial perfusion). Regional wall motion assessment with gating assists with this interpretation.

FDG imaging for myocardial viability assessment requires patient preparation and metabolic manipulation to shift the myocardial energy substrate utilization to glucose. A number of protocols to accomplish this are available, including glucose loading and/or the use of insulin, or the hyperinsulinemic clamp [28]. Diabetic patients may require the latter [29] (see [ASNC/SNMMI Position Statement](#) [22]). Once the patient has been appropriately prepped, 5 to 15 mCi of FDG is then injected, and after a 45 to 60 minute delay, imaging of the heart is performed using either 2-D or 3-D mode. The resulting scan of metabolically active myocardium is compared with the perfusion images generally using standard views, a semiquantitative approach, and a 17-segment model.

PART IV FDG-PET Inflammation/Infection Imaging

XIII. INDICATIONS

FDG-PET is becoming a useful tool in the evaluation of myocardial inflammation and especially in cases of cardiac sarcoid. Other uses include myocarditis (especially viral Coxsackie) and various arteritides. FDG-PET assessment of cardiac disease can be challenging because the radiopharmaceutical accumulates in normal myocardium [30], thus obscuring visualization of myocardial uptake that is due to inflammation.

XIV. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the [ACR–SPR Technical Standard for Diagnostic Procedures Using Radiopharmaceuticals](#) [3].

XV. SPECIFICATIONS OF THE EXAMINATION

Physiologic FDG uptake in normal myocardium can range from none to focal or even diffuse uptake in the same person under varying physiologic conditions because uptake in the normal myocardium depends on the patient's fasting state and shift of myocyte metabolism from glucose to fatty acid [31]. A variety of patient preparations have been utilized with varying success for suppression of physiologic myocardial FDG uptake, including, but not limited to, prolonged fasting, dietary manipulations with high-fat, low-carbohydrate meals, or intravenous heparin. An acceptable approach to patient preparation is the use of combined low-carbohydrate meals the day before the PET examination followed by at least 12-hour fasting before PET can be used to suppress physiologic FDG uptake by normal myocytes. The success rate of this approach is not known but is estimated to be 80% to 90%. Exercise should be avoided for 24 hours before the PET examination. Following injection of the FDG (5 to 15 mCi), acquisition can be performed after a 60 to 90-min delay in either 2-D or 3-D mode but without gating, as images may have no or minimal myocardial FDG uptake for tracking of myocardial contours.

If there is clinical desire to assess for the presence of extracardiac sarcoid, a limited whole-body PET study using the same fludeoxyglucose FDG, or 18F-FDG, injection can be performed immediately following the dedicated cardiac 18F-FDG study.

To differentiate the spectrum of cardiac sarcoidosis and improve diagnostic accuracy, rest myocardial perfusion imaging is recommended in conjunction with FDG imaging. The perfusion images are generally performed prior to the FDG, using either 13N-ammonia or rubidium-82 and, as previously outlined, SPECT myocardial perfusion with either sestamibi or tetrofosmin, if 13N-ammonia or rubidium-82 are not available.

With PET/CT, the reconstructed PET and CT image sets must be accurately aligned for fusion and subsequent attenuation correction. A normal PET examination for cardiac sarcoidosis will show complete suppression of FDG from the myocardium and normal resting myocardial perfusion. Incomplete suppression of FDG from normal myocardium, as might occur because of inadequate patient preparation, may be accompanied by diffuse FDG uptake, usually with normal resting perfusion. In the presence of active inflammation, focal areas of FDG uptake may be present without or with perfusion defects. In the case of scarring/fibrosis, a resting perfusion defect without FDG uptake is present. Inflammation and scarring/fibrosis may coexist in the same patient and may lead to several patterns of perfusion and metabolism in the left ventricle.

XVI. DOCUMENTATION

Reporting should be in accordance with the [ACR Practice Parameter for Communication of Diagnostic Imaging Findings](#) [32].

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

XVII. RADIATION SAFETY [33,34]

Radiologists, medical physicists, registered radiologist assistants, radiologic technologists, and all supervising physicians have a responsibility for safety in the workplace by keeping radiation exposure to staff, and to society as a whole, "as low as reasonably achievable" (ALARA) and to assure that radiation doses to individual patients are appropriate, taking into account the possible risk from radiation exposure and the diagnostic image quality necessary to achieve the clinical objective. All personnel that work with ionizing radiation must understand the key principles of occupational and public radiation protection (justification, optimization of protection, and application of dose limits) and the principles of proper management of radiation dose to patients (justification, optimization, and the use of dose reference levels). Please consult http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1578_web-57265295.pdf.

Facilities and their responsible staff should consult with the radiation safety officer to ensure that there are policies and procedures for the safe handling and administration of radiopharmaceuticals and that they are adhered to in accordance with ALARA. These policies and procedures 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.

Nationally developed guidelines, such as the [ACR Appropriateness Criteria](#)[®], should be used to help choose the most appropriate imaging procedures to prevent unwarranted radiation exposure.

Additional information regarding patient radiation safety in imaging is available at the Image Gently[®] for children (www.imagegently.org) and Image Wisely[®] for adults (www.imagewisely.org) websites. These advocacy and awareness campaigns provide free educational materials for all stakeholders involved in imaging (patients, technologists, referring providers, medical physicists, and radiologists).

Radiation exposures or other dose indices should be measured and patient radiation dose estimated for representative examinations and types of patients by a Qualified Medical Physicist in accordance with the applicable ACR Technical Standards. Regular auditing of patient dose indices should be performed by comparing the facility's dose information with national benchmarks, such as the ACR Dose Index Registry, the NCRP Report No. 172, Reference Levels and Achievable Doses in Medical and Dental Imaging: Recommendations for the United States, or the Conference of Radiation Control Program Director's National Evaluation of X-ray Trends. (ACR Resolution 17 adopted in 2006—revised in 2009, 2013, Resolution 52).

XVIII. 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 website (<https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement>).

Equipment performance monitoring should be in accordance with the [ACR–AAPM Technical Standard for Nuclear Medical Physics Performance of Gamma Cameras](#) [35].

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