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

The American College of Radiology, with more than 40,000 members, is the principal organization of radiologists, radiation oncologists, and clinical medical physicists in the United States. The College is a nonprofit professional society whose primary purposes are to advance the science of radiology, improve radiologic services to the patient, study the socioeconomic aspects of the practice of radiology, and encourage continuing education for radiologists, radiation oncologists, medical physicists, and persons practicing in allied professional fields.

The American College of Radiology will periodically define new practice parameters and technical standards for radiologic practice to help advance the science of radiology and to improve the quality of service to patients throughout the United States. Existing practice parameters and technical standards will be reviewed for revision or renewal, as appropriate, on their fifth anniversary or sooner, if indicated.

Each practice parameter and technical standard, representing a policy statement by the College, has undergone a thorough consensus process in which it has been subjected to extensive review and approval. The practice parameters and technical standards recognize that the safe and effective use of diagnostic and therapeutic radiology requires specific training, skills, and techniques, as described in each document. Reproduction or modification of the published practice parameter and technical standard by those entities not providing these services is not authorized.

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 care[1]. 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 considering 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 variables such as the condition of the patient, limitations of available resources, or advances in knowledge or technology after publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document may consider documenting in the patient record information sufficient to explain the approach taken.

The practice of medicine involves the science, and 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 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, 831 N.W.2d 826 (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 American College of Nuclear Medicine (ACNM), 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).

This practice parameter 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 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–ACNM–SNMMI–SPR–STR Practice Parameter for the Use of Radiopharmaceuticals in Diagnostic Procedures [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. Parts 3, 4, and 5 discuss imaging of myocardial viability, cardiac inflammation, and cardiac amyloidosis.

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. Calcium scoring, quantitative or qualitative, should be provided when possible if computed tomography (CT) images are obtained as part of the study [4].

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 in neoplasms may result in abnormal uptake and should be reported if seen (eg, breast cancer can be incidentally detected during stress testing). Attenuation correction CT should be reviewed for incidental findings (eg, lung nodules/masses, bulky lymphadenopathy).

II. INDICATIONS AND CONTRAINDICATIONS

Myocardial perfusion imaging encompasses single-photon emission CT (SPECT), positron emission tomography (PET), imaging at stress and/or rest, and gated or ungated imaging. Indications for these examinations include, but are not limited to, the following [5]:

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 [6]
7. Stratifying the risk after myocardial infarction
8. Evaluating ventricular function and measuring ventricular volumes using gated images
9. Evaluating congenital cardiovascular disease including pre- and postinterventions or surgery [7]

The ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Patients with Ionizing Radiation [8] 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.

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR–ACNM–SNMMI–SPR Practice Parameter for the Use of Radiopharmaceuticals in Diagnostic Procedures [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)

IV. SPECIFICATIONS OF THE EXAMINATION

A. Radiopharmaceutical

1. Technetium-99m (Tc99m) sestamibi and Tc99m tetrofosmin
   Sestamibi and tetrofosmin are taken up by the myocardium proportional to 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 15–120 minutes after administration of the radiopharmaceutical. Numerous imaging protocols have been described (eg, one-day rest/stress, one-day stress first or stress only, two-day stress/rest, and rest thallium-stress sestamibi or other dual-radiopharmaceutical techniques) [9]. Protocol selection should reflect the needs of the patient and the logistics of the institution. One-day total administered activity of up to 1.63 GBq (44 mCi) 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 (ie, 296 MBq [8 mCi] for rest imaging, followed by 888 MBq [24 mCi] for stress imaging). The stress injection should be given 1–2 minutes before cessation of exercise or at maximal pharmacologic stress. 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 [10,11]. Routine use of thallium and dual-isotope protocols, such as rest thallium-stress sestamibi, is discouraged because of the higher patient radiation exposure (due to the use of thallium instead of Tc99m-based agents) without significant clinical benefits. In children, please refer to the North American Consensus Guidelines for Pediatric Administered Radiopharmaceutical Activities [12]. SPECT/CT allows for routine CT attenuation correction image sets as well as coronary calcium scoring.

2. Thallium-201 (thallous chloride)
   Thallium-201 has significantly higher radiation dose than the Tc99m-labeled radiopharmaceuticals, combined with lower image quality, 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)- PET or cardiac magnetic resonance imaging (MRI) is preferred. The protocol for thallium viability imaging is simpler than FDG viability imaging, and may be more feasible, though, depending on staffing and equipment availability. Thallium is injected intravenously in administered activity of 74–148 MBq (2.0–4.0 mCi) . For an exercise

examination, radiopharmaceutical injection should occur one minute before cessation of exercise or at maximal pharmacological stress. Imaging is routinely started within 10 minutes after injection. Redistribution images are obtained 3–4 hours after injection, with or without the additional reinjection of 37 MBq (1.0 mCi) of thallium. If reinjection of 37 MBq (1.0 mCi) of thallium is planned before redistribution imaging, the administered activity used for stress imaging may be limited to 111 Mbq (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.

3. 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, ability to assess quantitative myocardial perfusion with flow reserves, and reduced patient radiation exposure compared with Tc99m perfusion agents. The studies are almost always performed with pharmacologic stress, though treadmill stress is possible if planned appropriately [13,14]. 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. Rapid ammonia perfusion protocols using 9 mCi and 18 mCi after two half lives, with the subtraction of residual activity for calculation of myocardial blood flow can reduce the conventional imaging protocol timeline. PET/CT allows for routine CT attenuation correction image sets as well as coronary calcium scoring[15,16]. 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.

IV. SPECIFICATIONS OF THE EXAMINATION

B. Patients and Preparation

Patients should be evaluated before the examination for appropriateness of the test and 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 before exercise of pharmalogic stress. They may have sugar-free beverages before the redistribution phase of a thallium examination but otherwise they should remain fasting and not exercise more than is absolutely neccessary. Because all xanthines (eg, caffeine and theophylline) interfere with the pharmacologic effect of dipyridamole and adenosine, they must be discontinued for 24–48 hours before the examination if these agents are to be used.

IV. SPECIFICATIONS OF THE EXAMINATION

C. 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 and is required for Rubidium-82 due to its extremely short half-life. Exercise is feasible with Nitrogen-13 ammonia but has many practical challenges and may have adverse effects on image quality that are due to respiratory patient motion. Flupiridaz has a significantly longer half time (T1/2 = 110 min), which permits exercise testing; however, at this time, flurpiridaz is not FDA approved.

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.

1. 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/h) 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 webpage . 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 (and this should be noted in the report). One solution is to convert exercise tests to pharmacologic to assure adequate stress level. 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 [17]. Depending on the clinical necessity or the clinical question, these medications may need to be discontinued by the patient's physician before 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.

2. Pharmacologic
   The heart may be stressed using one of a variety of pharmaceutical medications, but a vasodilator stress agent (eg, adenosine, dipyridamole, or regadenoson) is preferred for radionuclide myocardial perfusion imaging unless a contraindication exists, in which case dobutamine (which increases myocardial oxygen demand) 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 before examination for a time sufficient to obviate their pharmacologic effect.

   a. 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 2–4 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. Relative contraindications to the use of the medicine include patients with unstable angina, bronchospastic airway disease, and second-degree or third-degree atrioventricular (AV) block without a functioning pacemaker due to increased risk for complications of dipyridamole administration. As with physical stress, clinical monitoring with blood pressure and ECG surveillance is mandatory during the dipyridamole infusion and after infusion.

   b. Adenosine is given intravenously in a dosage of 0.14 mg/kg/min over 6 minutes (3 minutes before 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 2–2.5 minutes before 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 similar interference as dipyridamole, from xanthine-containing foods, beverages, and medications, so all must be discontinued for 24–48 hours before examination. Significant bronchospastic airway disease, second- or third-degree AV block or sinus node disease without a functioning pacemaker, systolic blood pressure <90 mm Hg, and recent (<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 and ECG monitoring is mandatory throughout the procedure.

c. Regadenoson is a selective A2A adenosine receptor agonist administered as a rapid intravenous injectionat a fixed dose 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 AV block or sinus node dysfunction who do not have a functioning artificial pacemaker. Systolic blood pressure <90 mm Hg and recent (<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 [18]. The agent may lower seizure threshold, and aminophylline should not be used in cases of seizures associated with regadenoson.

d. 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, to improve image quality, or for those who were unable to achieve adequate exercise (<5 METS and <85% MPHR). While using dipyridamole, exercise should start after the completion of dipyridamole infusion and should last 4–6 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.

e. Dobutamine is infused intravenously. A number of protocols are available. One involves the graduated infusion of increasing amounts of dobutamine over time, beginning with 5–10 mcg/kg/min over 3-minute increments, rising by 5–10 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 MPHR 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.

IV. SPECIFICATIONS OF THE EXAMINATION

D. 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.

IV. SPECIFICATIONS OF THE EXAMINATION

E. Imaging

For most applications, SPECT, SPECT/CT, PET, or PET/CT should be performed [19,20]. Planar imaging is no longer the standard of care. If a patient is unable to tolerate SPECT imaging, consider another modality for ischemic evaluation.

1. 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 their 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 fistula injury. Patients should wear similar, loose-fitting clothing for both sets of images. To avoid inconsistent attenuation artifacts in a patient, special care should be taken to position the patient's breasts as identically as possible between the stress and rest images.

   The imaging protocol should be chosen for optimum quality and should be consistent from patient to patient. Iterative reconstruction protocols, commonly available from vendors, are recommended and afford better image quality.

   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 [21]. Other useful quality control images are the summed projection images. Improper reconstruction techniques can also produce artifacts [22,23]. 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 Tc99m–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 [24-27]. In such cases, manufacturers' suggested protocols should be followed [19-21].

2. 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.

IV. SPECIFICATIONS OF THE EXAMINATION

F. Interpretation

For both SPECT and PET myocardial perfusion imaging, myocardial perfusion images are 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 [28]. Global left ventricular systolic function and left ventricular size are generally assessed quantitatively and qualitatively. Regional wall motion is assessed using a combination of visual 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.

IV. SPECIFICATIONS OF THE EXAMINATION

G. Quantification

A number of strategies are available for quantitative analysis of PET and SPECT myocardial perfusion studies. Quantitative SPECT 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 in 2018. To assure accuracy of PET quantification data, strict adherence to the protocol and consistent injection method is required. Quality control is extremely important, including thorough review of the rest and stress perfusion curves, spillover fraction, and motion. Benefits include the identification of "balanced ischemia" in which all heart segments do not augment blood flow to expected normal levels between rest and stress due to significant and diffuse coronary disease but appear similar to all other segments due to the diffuse involvement, leading to the imaging appearance of normal perfusion. There are large observational studies and multiple position papers/guidelines detailing the prognostic importance of PET-derived myocardial blood flow. Investigations are ongoing in this area for SPECT.

V. EQUIPMENT SPECIFICATIONS

1. Planar

   Currently, planar imaging has largely been replaced by SPECT and PET imaging. If SPECT/PET cannot be performed then another methodology to assess ischemia or coronary artery disease should be employed (eg, echocardiography, cardiac MRI, or CT).

2. SPECT

   SPECT acquisition parameters depend on the radiopharmaceutical and instrument [19,20]. 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, with low-energy, high-resolution collimators, 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.
   The greater availability of hybrid SPECT/CT systems allows for attenuation correction, an assessment of coronary artery calcification, which may be clinically significant and should be reported [29-31].
   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 semi-upright 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 8–16 time frames per R-R interval, in a manner similar to SPECT-gated perfusion studies but at higher spatial resolution. Because image acquisition is performed immediately following stress, peak stress ejection fraction can be assessed, and a lack of augmentation of stress ejection fraction carries diagnostic and prognosti value (NEED REFS here). List-mode acquisitions are now available with nearly all cameras, which enable simultaneous dynamic and ECG-gated acquisitions (see ASNC/SNMMI Position Statement [32]). With PET/CT the reconstructed PET and CT image sets must be accurately aligned for fusion and subsequent attenuation correction.

I. 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

Although this is a viable technique, echocardiography and Cardiac MRI have largely replaced nuclear 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 [33].

II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR–ACNM–SNMMI–SPR Practice Parameter for the Use of Radiopharmaceuticals in Diagnostic Procedures [3].

III. 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)

III. SPECIFICATIONS OF THE EXAMINATION

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

1. Radiopharmaceutical [34-37]

Tc99m–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 555–925 MBq (15–25 mCi) 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 185–740 MBq (5–20 mCi) [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 Tc99m. Other medications may have similar effects. In patients with a history of heparin allergy or heparin-induced thrombocytopenia (HIT), alternative anticoagulation can be employed using Anticoagulant Citrate Dextrose (ACD) solution [38-40]. In children, please refer to the North American Consensus Guidelines for Pediatric Administered Radiopharmaceutical Activities [12].

III. SPECIFICATIONS OF THE EXAMINATION

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

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.

III. SPECIFICATIONS OF THE EXAMINATION

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

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 2–3 minutes during each level of exercise by imaging after heart rate equilibration, which usually occurs in 1–2 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.

While this may be a viable technique, stress equilibrium radionuclide angiocardiography (ERNA) has largely been replaced by SPECT or PET myocaridal perfusion imaging (MPI), and can rarely be employed in a research setting.

III. SPECIFICATIONS OF THE EXAMINATION

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

4. Safety

Specific care must be taken during red blood cell (RBC) labeling to avoid misadministration of blood products. 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.

III. SPECIFICATIONS OF THE EXAMINATION

A.

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

5. Imaging

a. Rest

At least 16 frames (and up to 32 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 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° 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 1–2 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.

III. SPECIFICATIONS OF THE EXAMINATION

A.

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

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 >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, making sure that 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. SPECT MUGA can be used for volumetric calculation of left ventricular (LV) and right ventricular ejection fraction (RVEF).

III. SPECIFICATIONS OF THE EXAMINATION

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

While this is a viable technique, especially to calculate shunt fractions, echocardiography and Cardiac MRI have largely replaced nuclear evaluation.

III. SPECIFICATIONS OF THE EXAMINATION

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

1. Radiopharmaceutical [34-37]

If the examination is performed in conjunction with a gated blood-pool examination, Tc99m-labeled RBC in an administered activity of 555–925 MBq (15–25 mCi) may be used. Other Tc99m-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 185–740 MBq (5–10 mCi). 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. In children, please refer to the North American Consensus Guidelines for Pediatric Administered Radiopharmaceutical Activities [12].

III. SPECIFICATIONS OF THE EXAMINATION

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

2. Patient

No patient preparation is required unless the procedure is performed as part of an exercise examination.

III. SPECIFICATIONS OF THE EXAMINATION

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

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.

III. SPECIFICATIONS OF THE EXAMINATION

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

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.

III. SPECIFICATIONS OF THE EXAMINATION

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

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) [7,41,42].

Note: Right-to-Left Shunt Detection: For further information see the ACR–SPR–STR Practice Parameter for the Performance of Pulmonary Scintigraphy [33].

IV. 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.

I. INDICATIONS

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

II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR–ACNM–SNMMI–SPR Practice Parameter for the Use of Radiopharmaceuticals in Diagnostic Procedures [3].

III. 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 use to glucose. A number of protocols to accomplish this are available, including glucose loading and/or the use of insulin, or the hyperinsulinemic clamp [43]. Patients with diabetes may require the latter [44] (see ASNC/SNMMI Position Statement [32]). Once the patient has been appropriately prepped, 185–555 MBq (5–15 mCi) of FDG is then injected, and after a 45–60 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.

I. 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 [45], thus obscuring visualization of myocardial uptake that is due to inflammation.

II. QUALIFICATIONS AND RESPONSIBLITIES OF PERSONNEL

See the ACR–ACNM–SNMMI–SPR Practice Parameter for the Use of Radiopharmaceuticals in Diagnostic Procedures [3].

III. 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 [46]. A variety of patient preparations have been used 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 [47], or intravenous heparin. One approach to patient preparation is the use of combined high-fat, low-carbohydrate meals, 24–48 hours before the day before the PET examination followed by at least 12-hour fasting before PET to suppress physiologic FDG uptake by normal myocytes. The success rate of this approach is not known but is estimated to be 80%–90%. [Ref] Exercise should be avoided for 24 hours before the PET examination. Following injection of the FDG (5–15 mCi), acquisition can be performed after a 60–90-min delay in either 2-D or 3-D mode but without gating, because images may have no or minimal myocardial FDG uptake for tracking of myocardial contours.

Performance of limited whole-body PET is recommended to assess for the presence of extracardiac sarcoid, and this can be performed using the same 18F-FDG injection 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 before 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 with or without 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.

Assessment of cardiac sarcoidosis can be performed with simultaneous PET/MR, which allows for comprehensive evaluation of cardiac morphology and function with excellent soft-tissue characterization. Areas of myocardial FDG uptake indicative of active inflammatory process can be compared with extend of scarring assessed by late gadolinium enhancement imaging. Other etiologies of cardiac dysfunction can be excluded (eg, amyloidosis, valvular disease).

I. INDICATIONS

The use of nuclear imaging with bone-avid tracers (pyrophosphate [PYP]/hydroxymethylene diphosphonate [HMDP] or 3,3-diphosphono-1,2-propanodicarboxylic acid [DPD]) is a recent significant advance in diagnosing cardiac transthyretin amyloidosis (ATTR) with high accuracy.

99m Technetium pyrophosphate (99mTc-PYP) planar and SPECT imaging, as well as 99mTc-3,3-diphosphono-1,2-propanodicarboxylic acid (99mTc-DPD), and 99mTc-hydroxymethylene diphosphonate (99mTc-HMDP) imaging are used for the evaluation of ATTR. The use of technetium-labeled cardiac scintigraphy has become increasingly widespread as new treatments have become available compounded with studies suggesting a high prevalence of wild-type cardiac ATTR in as many as 10%–16% of older patients with heart failure or aortic stenosis [48].

Indications include but are not limited to screening for cardiac amyloidosis in patients with clinical suspicion for cardiac amyloidosis, specifically patients with heart failure and unexplained myocardial hypertrophy, and patients over 60 years of age with unexplained heart failure and preserved ejection fraction, screening in asymptomatic TTR gene carriers or patients with known or suspected familial amyloidosis, and diagnosis of cardiac ATTR in individuals with cardiac magnetic resonance or echocardiography suggestive of cardiac amyloidosis [49].

II. QUALIFICATIONS AND RESPONSIBILITES OF PERSONNEL

See the ACR–ACNM–SNMMI–SPR Practice Parameter for the Use of Radiopharmaceuticals in Diagnostic Procedures [3].

III. SPECIFICATIONS OF THE EXAMINATION

A. Radiopharmaceutical

A range of 70–740 MBq (10–20 mCi) of 99mTc-PYP are given intravenously. The radiotracer is theorized to bind to the microcalcifications in the amyloid fibrils. Qualitative and quantitative methods are used to grade the degree of uptake on planar imaging. SPECT is useful to confirm myocardial uptake and exclude blood-pool activity or overlapping bone.

III. SPECIFICATIONS OF THE EXAMINATION

B. Patient

No specific patient preparation is required. However, as light-chain amyloidosis is a cause of misdiagnosis, patients should be assessed by serum-free light-chain assay and serum and urine immunofixation to exclude a clonal plasma cell process.

III. SPECIFICATIONS OF THE EXAMINATION

C. Imaging

Planar imaging including anterior and lateral views can be acquired early at 1 hour or late at 3 hours. Three-hour imaging is less likely to have blood-pool activity. SPECT/CT imaging with CT for attenuation correction is helpful to localize tracer uptake to the myocardium. The use of 1 hour planar-only imaging is not recommended.

III. SPECIFICATIONS OF THE EXAMINATION

D. Interpretation

While planar images are obtained and reviewed, reconstructed SPECT images should be reviewed in standard cardiac imaging planes, with the presence of uptake on SPECT being the diagnostic standard. Myocardial uptake patterns are categorized as absent, focal, focal on diffuse, or diffuse [50]. Myocardial uptake is graded in a semiquantitative manner using a visual scoring method relative to rib/bone uptake, where:

Grade 0 = no uptake,

Grade 1 = uptake less than rib,

Grade 2 = uptake equal to rib,

Grade 3 = uptake greater than rib.

Grade 2 or 3 uptake is considered strongly suggestive of ATTR amyloidosis.

Myocardial uptake can also be quantified on planar imaging using a myocardial to contralateral lung ratio by placing a region of interest over the heart and mirrored over the contralateral chest to account for background and rib uptake.

At one hour, a ratio greater than or equal to 1.5 is suggestive of ATTR amyloidosis. A ratio less than 1 is considered not suggestive, and a ratio between 1.0 and less than 1.5 is considered equivocal for TTR amyloidosis.

The use of SPECT/CT is beneficial to confirm myocardial uptake and exclude causes of false positive scans such as blood-pool activity and significantly limit equivocal test results. An overall interpretation of the examination should be provided as:

(1) not suggestive,

(2) strongly suggestive,

(3) equivocal for ATTR amyloidosis.

Any ancillary findings as well as interpretation of any extracardiac findings should be included in the report for scintigraphy and CT if performed.

IV. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [51].

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.

V. EQUIPMENT SPECIFICATIONS

Equipment performance monitoring should be in accordance with the ACR–AAPM Technical Standard for Nuclear Medical Physics Performance of Gamma Cameras [52].

VI. RADIATION SAFETY [53-54]

Radiologists, medical physicists, non-physician radiology providers**,** 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 who work with ionizing radiation must understand the key principles of occupational and public radiation protection (justification, optimization of protection, application of dose constraints and limits) and the principles of proper management of radiation

dose to patients (justification, optimization including the use of dose reference levels). https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1775_web.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 in accordance with ALARA principles. 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 applicable state, local, or other relevant regulatory agencies and accrediting bodies, as appropriate. Quantities of radiopharmaceuticals should be tailored to the individual patient by prescription or protocol, using body habitus or other customized method when such guidance is available.

Nationally developed guidelines, such as the ACR's Appropriateness Criteria®, should be used to help choose the most appropriate imaging procedures to prevent unnecessary radiation exposure.

Additional information regarding patient radiation safety in imaging is available from the following websites – Image Gently® for children (www.imagegently.org) and Image Wisely® for adults (www.imagewisely.org). 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 periodically measured by a Qualified Medical Physicist in accordance with the applicable ACR Technical Standards. Monitoring or regular review of dose indices from patient imaging should be performed by comparing the facility's dose information with national benchmarks, such as the ACR Dose Index Registry and relevant publications relying on its data, applicable ACR Practice Parameters, 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; 2006, 2009, amended 2013, revised 2023 (Res. 2d).

VII. 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).

ACKNOWLEDGEMENTS

This practice parameter was revised according to the process described under the heading *The Process for Developing ACR Practice Parameters and Technical Standards* on the ACR website (https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards) by the Committee on Practice Parameters – Nuclear Medicine and Molecular Imaging of the ACR Commission on Nuclear Medicine and Molecular Imaging and by the Committee on Practice Parameters – Pediatric Radiology of the ACR Commission on Pediatric Radiology, in collaboration with the ACNM, the NASCI, the SNMMI, the SPR, and the STR.

Writing Committee – members represent their societies in the initial and final revision of this practice parameter

ACR
Wymer, David C MD, Chair
Henkel, Jacqueline MD
Trout, Andrew T MD

STR
Cronin, Paul Patrick

ACNM
Fotos, Joseph S MD
Garg, Sumit MD

NASCI
Kusmirek, Joanna E MD

SNMMI
Malhotra, Saurabh MD, MPH
Weinberg, Richard MD

SPR
Treves, S. Ted MD

Committee on Practice Parameters – Nuclear Medicine and Molecular Imaging
(ACR Committee responsible for sponsoring the draft through the process)

Ghesani, Munir V MD, Chair
Aboian, Mariam MD, PhD
Bartel, Twyla B DO, MBA
Gerard, Perry S MD
Marcus, Charles MD
Peacock, Justin G MD, PhD
Surasi, Devaki Shilpa MD
Wong, Terence Z MD, PhD
Subramaniam, Rathan M MBA, MD, MPH, PhD, Chair
Akin, Esma A MD
Dibble, Elizabeth H MD
Karagulle Kendi, A. Tuba MD
Mercier, Gustavo A MD, PhD
Solnes, Lilja B MBA, MD
Trout, Andrew T MD
Zukotynski, Katherine MD, PhD

Committee on Practice Parameters and Technical Standards
(ACR Committee responsible for sponsoring the draft through the process)

Newell, Mary S MD, Chair
Caplin, Drew M MD

Committee on Practice Parameters – Pediatric Imaging
(ACR Committee responsible for sponsoring the draft through the process)

Levin, Terry L MD, Chair
Amodio, John B MD
Blumfield, Einat MD
Goldman-Yassen, Adam MD
Lala, Shailee V MD
Laufer, Adina MD
Maloney, John A MD
Shah, Summit MD
Vatsky, Seth DO
Alizai, Hamza MD
Betz, Bradford W MD
Collard, Michael MD
Lai, Hollie A MD
Lasiecka, Zofia M MD, PhD
Li, Arleen MD
Noda, Sakura MD
Trout, Andrew T MD

Barth, Richard MD, Chair, Commission on Pediatric Radiology
Larson, David B MBA, MD, Chair, Commission on Quality and Safety
Rohren, Eric MD, PhD, Chair, Commission on Nuclear Medicine & Molecular Imaging

Comments Reconciliation Committee

Batlle, Juan C MBA, MD - CSC, Chair
Ghesani, Munir V MD, Co-Chair
Subramaniam, Rathan M MBA, MD, MPH, PhD, Co-Chair
Bartel, Twyla B DO, MBA
Caplin, Drew M MD
Crummy, Timothy MD, MHA - CSC
Garg, Sumit MD
Kusmirek, Joanna E MD
Malhotra, Saurabh MD, MPH
Rohren, Eric MD, PhD
Treves, S. Ted MD
Weinberg, Richard MD
Boyd, David MBA, MD - CSC, Co-Chair
Levin, Terry L MD, Chair
Amodio, John B MD
Barth, Richard MD
Cronin, Paul Patrick
Fotos, Joseph S MD
Henkel, Jacqueline MD
Larson, David B MBA, MD
Newell, Mary S MD
Schoppe, Kurt MD - CSC
Trout, Andrew T MD
Wymer, David C MD

REFERENCES

1. Dae MW. Pediatric nuclear cardiology. Seminars in nuclear medicine 2007;37:382-90.
2. Nadel HR, Stilwell ME. Cardiopulmonary Scintigraphy in Children. Nuclear Medicine Annual 1998:165-224.
3. American College of Radiology. ACR–ACNM–SNMMI–SPR Practice Parameter for the Use of Radiopharmaceuticals in Diagnostic Procedures Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/Radiopharmaceuticals.pdf?la=en. Accessed January 29, 2023.
4. Trpkov C, Savtchenko A, Liang Z, et al. Visually estimated coronary artery calcium score improves SPECT-MPI risk stratification. Int J Cardiol Heart Vasc 2021;35:100827.
5. Hendel RC, Berman DS, Di Carli MF, et al. ACCF/ASNC/ACR/AHA/ASE/SCCT/SCMR/SNM 2009 Appropriate Use Criteria for Cardiac Radionuclide Imaging: A Report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, the American Society of Nuclear Cardiology, the American College of Radiology, the American Heart Association, the American Society of Echocardiography, the Society of Cardiovascular Computed Tomography, the Society for Cardiovascular Magnetic Resonance, and the Society of Nuclear Medicine. Journal of the American College of Cardiology 2009;53:2201-29.
6. Ghatak A, Hendel RC. Role of imaging for acute chest pain syndromes. Seminars in nuclear medicine 2013;43:71-81.
7. Treves ST. *Pediatric Nuclear Medicine and Molecular Imaging.* 4 ed. New York, NY: Springer; 2014.
8. American College of Radiology. ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Patients With Ionizing Radiation. Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/pregnant-pts.pdf?la=en. Accessed January 30, 2023.
9. Henzlova MJ, Duvall WL, Einstein AJ, Travin MI, Verberne HJ. ASNC imaging guidelines for SPECT nuclear cardiology procedures: Stress, protocols, and tracers. Journal of nuclear cardiology : official publication of the American Society of Nuclear Cardiology 2016;23:606-39.
10. Chang SM, Nabi F, Xu J, Raza U, Mahmarian JJ. Normal stress-only versus standard stress/rest myocardial perfusion imaging: similar patient mortality with reduced radiation exposure. Journal of the American College of Cardiology 2010;55:221-30.
11. Duvall WL, Wijetunga MN, Klein TM, et al. The prognosis of a normal stress-only Tc-99m myocardial perfusion imaging study. Journal of nuclear cardiology : official publication of the American Society of Nuclear Cardiology 2010;17:370-7.
12. Treves ST, Gelfand MJ, Fahey FH, Parisi MT. 2016 Update of the North American Consensus Guidelines for Pediatric Administered Radiopharmaceutical Activities. Journal of nuclear medicine : official publication, Society of Nuclear Medicine 2016;57:15n-18n.
13. Harland DR, Galazka PZ, Rasmussen J, Mahlum D, Falk J, Port SC. Feasibility of exercise treadmill (13)N-ammonia positron emission tomography myocardial perfusion imaging using an off-site cyclotron. Journal of nuclear cardiology : official publication of the American Society of Nuclear Cardiology 2022;29:938-45.
14. Chow BJ, Ananthasubramaniam K, dekemp RA, Dalipaj MM, Beanlands RS, Ruddy TD. Comparison of treadmill exercise versus dipyridamole stress with myocardial perfusion imaging using rubidium-82 positron emission tomography. Journal of the American College of Cardiology 2005;45:1227-34.
15. Pieszko K, Shanbhag AD, Lemley M, et al. Reproducibility of quantitative coronary calcium scoring from PET/CT attenuation maps: comparison to ECG-gated CT scans. Eur J Nucl Med Mol Imaging 2022;49:4122-32.
16. Fathala A, Aboulkheir M, Bukhari S, Shoukri MM, Abouzied MM. Benefits of adding coronary calcium score scan to stress myocardial perfusion positron emission tomography imaging. World J Nucl Med 2019;18:149-53.
17. Yoon AJ, Melduni RM, Duncan SA, Ostfeld RJ, Travin MI. The effect of beta-blockers on the diagnostic accuracy of vasodilator pharmacologic SPECT myocardial perfusion imaging. Journal of nuclear cardiology : official publication of the American Society of Nuclear Cardiology 2009;16:358-67.
18. Astellas Pharma US I. LEXISCAN® (regadenoson) injection, solution; 2018.
19. DePuey EG. Advances in SPECT camera software and hardware: currently available and new on the horizon. Journal of nuclear cardiology : official publication of the American Society of Nuclear Cardiology 2012;19:551-81; quiz 85.
20. Travin MI. Cardiac cameras. Seminars in nuclear medicine 2011;41:182-201.

21. Bateman TM, Cullom SJ. Attenuation correction single-photon emission computed tomography myocardial perfusion imaging. Seminars in nuclear medicine 2005;35:37-51.
22. Fricke E, Fricke H, Weise R, et al. Attenuation correction of myocardial SPECT perfusion images with low-dose CT: evaluation of the method by comparison with perfusion PET. Journal of nuclear medicine : official publication, Society of Nuclear Medicine 2005;46:736-44.
23. Goetze S, Wahl RL. Prevalence of misregistration between SPECT and CT for attenuation-corrected myocardial perfusion SPECT. Journal of nuclear cardiology : official publication of the American Society of Nuclear Cardiology 2007;14:200-6.
24. Sharir T, Slomka PJ, Hayes SW, et al. Multicenter trial of high-speed versus conventional single-photon emission computed tomography imaging: quantitative results of myocardial perfusion and left ventricular function. Journal of the American College of Cardiology 2010;55:1965-74.
25. DePuey EG, Bommireddipalli S, Clark J, Thompson L, Srour Y. Wide beam reconstruction "quarter-time" gated myocardial perfusion SPECT functional imaging: a comparison to "full-time" ordered subset expectation maximum. Journal of nuclear cardiology : official publication of the American Society of Nuclear Cardiology 2009;16:736-52.
26. Ali I, Ruddy TD, Almgrahi A, Anstett FG, Wells RG. Half-time SPECT myocardial perfusion imaging with attenuation correction. Journal of nuclear medicine : official publication, Society of Nuclear Medicine 2009;50:554-62.
27. Dorbala S, Ananthasubramaniam K, Armstrong IS, et al. Single Photon Emission Computed Tomography (SPECT) Myocardial Perfusion Imaging Guidelines: Instrumentation, Acquisition, Processing, and Interpretation. Journal of nuclear cardiology : official publication of the American Society of Nuclear Cardiology 2018;25:1784-846.
28. Cerqueira MD, Weissman NJ, Dilsizian V, et al. Standardized Myocardial Segmentation and Nomenclature for Tomographic Imaging of the Heart. A statement for healthcare professionals from the Cardiac Imaging Committee of the Council on Clinical Cardiology of the American Heart Association. Circulation 2002;105:539-42.
29. Chang SM, Nabi F, Xu J, et al. The coronary artery calcium score and stress myocardial perfusion imaging provide independent and complementary prediction of cardiac risk. Journal of the American College of Cardiology 2009;54:1872-82.
30. Moser KW, O'Keefe JH, Jr., Bateman TM, McGhie IA. Coronary calcium screening in asymptomatic patients as a guide to risk factor modification and stress myocardial perfusion imaging. Journal of nuclear cardiology : official publication of the American Society of Nuclear Cardiology 2003;10:590-8.
31. Schepis T, Gaemperli O, Koepfli P, et al. Added value of coronary artery calcium score as an adjunct to gated SPECT for the evaluation of coronary artery disease in an intermediate-risk population. Journal of nuclear medicine : official publication, Society of Nuclear Medicine 2007;48:1424-30.
32. American Society of Nuclear Cardiology and Society of Nuclear Medicine and Molecular Imaging. Position statement on the clinical indications for myocardial perfusion. Available at: http://snmmi.files.cms-plus.com/ASNC_SNMMI_Joint_Statment_on_the_Clinical_Indications_for_Myocardial_Perfusion_PET%20-%20FINAL.pdf. Accessed January 8, 2018.
33. American College of Radiology. ACR–SPR–STR Practice Parameter for the Performance of Pulmonary Scintigraphy. Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/Pulmonary_Scintigraphy.pdf?la=en. Accessed January 27, 2023.
34. Hayes AM, Baker EJ, Kakadeker A, et al. Influence of anatomic correction for transposition of the great arteries on myocardial perfusion: radionuclide imaging with technetium-99m 2-methoxy isobutyl isonitrile. Journal of the American College of Cardiology 1994;24:769-77.
35. Imbriaco M, Cuocolo A, Pace L, et al. Technetium-99m methoxy isobutyl isonitrile simultaneous evaluation of ventricular function and myocardial perfusion in patients with congenital heart disease. Clinical nuclear medicine 1994;19:28-32.
36. Nakajima K, Taki J, Taniguchi M, Tonami N, Hisida K. Comparison of 99Tcm-sestamibi and 201Tl-chloride to estimate right ventricular overload in children. Nuclear medicine communications 1995;16:936-41.
37. Sobic-Saranovic DP, Pavlovic SV, Jovanovic IV, et al. Evaluation of myocardial perfusion and function by gated single-photon emission computed tomography technetium-99m methoxyisobutylisonitrile in children and adolescents with severe congenital heart disease. Nuclear medicine communications 2010;31:12-21.
38. Wieseler JF, Gebhard MW, Hung JC, Mullan BP, Wilson ME. In Vivo Comparison of Anticoagulant Citrate

Dextrose Versus Heparin for Use as an Anticoagulant with the UltraTag® Red Blood Cell Kit. Journal of Nuclear Medicine Technology 1994;22:178-81.
39. Hesse B, Lindhardt TB, Acampa W, et al. EANM/ESC guidelines for radionuclide imaging of cardiac function. Eur J Nucl Med Mol Imaging 2008;35:851-85.
40. Farrell MB, Galt JR, Georgoulias P, et al. SNMMI Procedure Standard/EANM Guideline for Gated Equilibrium Radionuclide Angiography. J Nucl Med Technol 2020;48:126-35.
41. James AE, Wagner HN, Cooke RE. *Pediatric Nuclear Medicine*. Philadelphia: W.B Saunders Company; 1974.
42. Treves S. Detection and quantitation of cardiovascular shunts with commonly available radionuclides. Seminars in nuclear medicine 1980;10:16-26.
43. Knuuti MJ, Nuutila P, Ruotsalainen U, et al. Euglycemic hyperinsulinemic clamp and oral glucose load in stimulating myocardial glucose utilization during positron emission tomography. Journal of nuclear medicine : official publication, Society of Nuclear Medicine 1992;33:1255-62.
44. Martin WH, Jones RC, Delbeke D, Sandler MP. A simplified intravenous glucose loading protocol for fluorine-18 fluorodeoxyglucose cardiac single-photon emission tomography. European journal of nuclear medicine 1997;24:1291-7.
45. James OG, Christensen JD, Wong TZ, Borges-Neto S, Koweek LM. Utility of FDG PET/CT in inflammatory cardiovascular disease. Radiographics : a review publication of the Radiological Society of North America, Inc 2011;31:1271-86.
46. Gropler RJ, Siegel BA, Lee KJ, et al. Nonuniformity in myocardial accumulation of fluorine-18-fluorodeoxyglucose in normal fasted humans. Journal of nuclear medicine : official publication, Society of Nuclear Medicine 1990;31:1749-56.
47. Harisankar CN, Mittal BR, Agrawal KL, Abrar ML, Bhattacharya A. Utility of high fat and low carbohydrate diet in suppressing myocardial FDG uptake. Journal of nuclear cardiology : official publication of the American Society of Nuclear Cardiology 2011;18:926-36.
48. Dorbala S, Ando Y, Bokhari S, et al. ASNC/AHA/ASE/EANM/HFSA/ISA/SCMR/SNMMI expert consensus recommendations for multimodality imaging in cardiac amyloidosis: Part 1 of 2-evidence base and standardized methods of imaging. Journal of nuclear cardiology : official publication of the American Society of Nuclear Cardiology 2019;26:2065-123.
49. Dorbala S, Ando Y, Bokhari S, et al. ASNC/AHA/ASE/EANM/HFSA/ISA/SCMR/SNMMI expert consensus recommendations for multimodality imaging in cardiac amyloidosis: Part 2 of 2-Diagnostic criteria and appropriate utilization. Journal of nuclear cardiology : official publication of the American Society of Nuclear Cardiology 2020;27:659-73.
50. Akincioglu C, Murthi M, Romsa J, Warrington J, Malhotra S. Comparison of cardio-focal and chest reconstruction of technetium-99m pyrophosphate scintigraphy for diagnosis of transthyretin cardiac amyloidosis: a quality assurance study. Journal of nuclear cardiology : official publication of the American Society of Nuclear Cardiology 2023.
51. American College of Radiology. ACR Practice Parameter for Communication of Diagnostic Imaging Findings. Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/communicationdiag.pdf?la=en. Accessed January 29, 2023.
52. American College of Radiology. ACR–AAPM Technical Standard for Nuclear Medical Physics Performance Monitoring of Gamma Cameras. Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/gamma-cam.pdf?la=en. Accessed January 27, 2023.
53. Cerqueira MD, Allman KC, Ficaro EP, et al. Recommendations for reducing radiation exposure in myocardial perfusion imaging. Journal of nuclear cardiology : official publication of the American Society of Nuclear Cardiology 2010;17:709-18.
54. Einstein AJ, Moser KW, Thompson RC, Cerqueira MD, Henzlova MJ. Radiation dose to patients from cardiac diagnostic imaging. Circulation 2007;116:1290-305.

*Practice parameters and technical standards are published annually with an effective date of October 1 in the year in which amended, revised or approved by the ACR Council. For practice parameters and technical standards published before 1999, the effective date was January 1 following the year in which the practice parameter or technical standard was amended, revised, or approved by the ACR Council.

Development Chronology for this Practice Parameter

1995 (Resolution 29)

Revised 2004 (Resolution 11)

Revised 1999 (Resolution 12)

Revised 2004 (Resolution 31a)

Amended 2006 (Resolution 35)

Revised 2009 (Resolution 14)

Sunset 2014 (Resolution 29)

2015 (Resolution 44)

Revised 2019 (Resolution 36)

Revised 2024 (Resolution 11)