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ACR–SPR–STR PRACTICE PARAMETER FOR THE PERFORMANCE OF CARDIAC POSITRON EMISSION TOMOGRAPHY - COMPUTED TOMOGRAPHY (PET/CT) IMAGING

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 has been developed collaboratively by the American College of Radiology (ACR), the Society for Pediatric Radiology (SPR), and the Society of Thoracic Radiology (STR). This document is intended to act as a guide for physicians performing and interpreting positron emission tomography–computed tomography (PET/CT) of cardiac diseases in adults and children.

When properly performed, cardiac PET is a sensitive means of demonstrating the biodistribution of radiopharmaceuticals within the heart and nearby vascular and nonvascular structures. As an independent modality, CT aids in the evaluation of cardiac disease. In cardiac PET/CT, CT is used for attenuation correction and anatomic coregistration of the PET image data. In this document, cardiac CT is discussed only in the context of cardiac PET/CT. For more specific details on cardiac CT, please refer to the [ACR–NASCI–SPR Practice Parameter for the Performance and Interpretation of Cardiac Computed Tomography \(CT\)](#) [1].

This practice parameter is limited to cardiac PET/CT imaging; it does not include all radiopharmaceuticals related to cardiac imaging and does not cover single-photon emission computed tomography (SPECT) imaging techniques. Application of this practice parameter should be done in accordance with the [ACR–SPR Technical Standard for Diagnostic Procedures Using Radiopharmaceuticals](#) [2]. For cardiac SPECT imaging, please refer to the [ACR–NASCI–SPR–STR Practice Parameter for the Performance of Cardiac Scintigraphy](#) [3].

II. INDICATIONS

The primary goals of cardiac PET/CT imaging include evaluation of perfusion, function, viability, inflammation, anatomy, and risk stratification for cardiac-related events such as myocardial infarction and death. Maximum diagnostic accuracy of cardiac PET/CT is achieved when images are interpreted in conjunction with other relevant imaging, clinical information, and laboratory data.

Clinical indications for cardiac PET/CT imaging include, but are not limited to:

1. Myocardial perfusion imaging (MPI) (CT may be used for coronary calcium scoring)
 - a. Detection of obstructive coronary artery disease causing myocardial ischemia in patients with acute or chronic chest pain
 - b. Risk assessment in asymptomatic high-risk patients
 - i. Evaluate patients with moderate or extensive plaque burden on prior calcium score CT
 - ii. Abnormal exercise stress tests
 - iii. Obese patients with likely suboptimal SPECT imaging
 - c. Clarification of equivocal or discordant prior tests
 - i. Borderline obstructive lesions in coronary angiography or by computed tomography angiography (CTA)
 - ii. Suspected artifacts on prior imaging (breast or diaphragmatic attenuation)
 - iii. Anomalous coronary arteries with suspected ischemia
 - d. Preoperative risk assessment before high-risk surgical procedures
 - e. Postoperative assessment of reimplanted coronary arteries (including congenital heart disease, eg, surgically corrected transposition of the great arteries)
 - f. Evaluation of cardiac function
2. Measurement of myocardial blood flow and coronary flow reserve and detection of balanced ischemia
3. Myocardial viability
 - a. Detection of hibernating or stunned myocardium
 - b. Preoperative assessment before revascularization for prognosis of improved left ventricular function
4. Cardiomyopathies including sarcoidosis, hypertrophic, Duchenne muscular dystrophy
5. Heart transplants

For information on radiation risks to the fetus, see the [ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation](#) [4].

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

A. Physicians

The supervising physician is responsible for all aspects of the study, including, but not limited to, reviewing all indications for the examination, specifying the imaging protocol to be performed, specifying the use and dosage of contrast and pharmacologic agents, specifying the methods of image reconstruction, assuring the quality of the images and of the final interpretation,² and communicating any critical or significant findings. For further information, please refer to the [ACR Practice Parameter for Communication of Diagnostic Imaging Findings](#) [5]. The supervising physician must be an Authorized User (AU) of radiopharmaceuticals or work under the auspices of another AU in their practice setting.

Physicians performing or supervising exercise or pharmacologic stress testing as part of cardiac PET/CT should meet the qualifications outlined in the [ACC/AHA Clinical Competence Statement on Stress Testing](#) [6]. Physicians supervising stress-induced examinations should have appropriate training in advanced cardiovascular life support.

1. Physicians with certification by the American Board of Radiology (ABR) in Diagnostic Radiology or in Nuclear Radiology or by the American Board of Nuclear Medicine (ABNM)

A physician who has been certified by the ABR or the ABNM has substantial knowledge of the principles of PET/CT image acquisition and postprocessing, including the design of PET/CT protocols and the use of diagnostic workstations. Physicians performing coronary CTA at the time of cardiac PET/CT should be knowledgeable of the administration, risks, and contraindications of medications which may be required for heart rate control (eg, beta-blockers, calcium channel blockers) and coronary vasodilatation (eg, nitroglycerin/nitrates) and of iodinated contrast media, including steps to reduce possible contrast media–related reactions and/or nephrotoxicity and to treat adverse reactions to contrast media (see [ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media](#) and the [ACR Manual on Contrast Media](#)) [7,8]. The physician should have substantial experience in CT interpretation, including CT assessment of extracardiac thoracic structures included in the cardiac PET/CT examination. However, in order to achieve competency in all aspects of cardiac PET/CT imaging, some physicians may require additional education in cardiac anatomy, physiology, pathology, and/or cardiac PET/CT imaging protocols and interpretation.

2. A physician board-certified or board-eligible by the American Board of Radiology (ABR) in Diagnostic Radiology, the ABR in Nuclear Radiology, and/or the American Board of Nuclear Medicine (ABNM)

The physician has substantial knowledge of the principles of PET/CT image acquisition and postprocessing, including the design of PET/CT protocols and the use of diagnostic workstations. A physician performing coronary CTA at the time of cardiac PET/CT should be knowledgeable of the administration, risks, and contraindications of medications which may be required for heart rate control (eg, beta-blockers, calcium channel blockers) and coronary vasodilatation (eg, nitroglycerin/nitrates) and of iodinated contrast media, including steps to reduce possible contrast media–related reactions and/or nephrotoxicity and to treat adverse reactions to contrast media (see [ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media](#) and the [ACR Manual on Contrast Media](#)) [7,8]. The physician should have substantial experience in CT interpretation, including CT assessment of extra-cardiac thoracic structures included in the cardiac PET/CT examination. However, in order to achieve

²The ACR Medical Legal Committee defines official interpretation as that written report (and any supplements or amendments thereto) that attach to the patient's permanent record. In healthcare facilities with a privilege delineation system, such a written report is prepared only by a qualified physician who has been granted specific delineated clinical privileges for that purpose by the facility's governing body upon the recommendation of the medical staff.

competency in all aspects of cardiac PET/CT imaging, some physicians may require additional education in cardiac anatomy, physiology, pathology, and/or cardiac PET/CT imaging protocols and interpretation.

A physician board-certified or board-eligible by the ABR and/or the ABNM should meet the following requirements:

- a. Completion of training in a program accredited by the Accreditation Council for Graduate Medical Education (ACGME), the Royal College of Physicians and Surgeons of Canada (RCPSC), the Collège des Médecins du Québec, or the American Osteopathic Association, (AOA) including 30 hours of education in cardiac anatomy, physiology, pathology, and cardiac PET/CT imaging.
or
Completion of 30 hours of Category 1 CME in cardiac imaging, including cardiac PET/CT, anatomy, physiology, and/or pathology or documented equivalent supervised experience.³
and
 - b. The interpretation, reporting, and/or supervised review of at least 50 cardiac PET/CT examinations during the previous 36 months. Live and/or on-line educational programs and/or proctored/over-read cardiac PET/CT cases may be used to fulfill this requirement.
3. A physician not board-certified or board-eligible by the ABR and/or the ABNM
The physician requires more extensive training and experience in cardiac PET/CT. In addition to specific training in image interpretation, this training must include the principles of PET/CT image acquisition and postprocessing, including the design of PET/CT protocols and the use of diagnostic workstations.

A physician not board-certified or board-eligible by the ABR and/or the ABNM must satisfy the following requirements:

- a. Completion of training in a program accredited by the ACGME, RCPSC, the Collège des Médecins du Québec, or AOA
and
- b. Completion of 30 hours of education in cardiac anatomy, physiology, pathology, and cardiac PET/CT imaging
and
- c. Completion of 200 hours of Cardiac 1 CME in the performance and interpretation of PET/CT
and
- d. Under supervision, interpretation and reporting of 300 cardiac radionuclide imaging cases, at least 50 of which must be cardiac PET/CT, during the past 36 months. Live and/or on-line educational programs and/or proctored/over-read cardiac PET/CT cases may be used to fulfill this requirement.

Administration of pharmacologic agents

A physician who is knowledgeable about the administration, risks, and contraindications of the pharmacologic agents must be immediately available throughout the stress procedure.

Maintenance of competence

For continuing education and experience, please see the [ACR–SPR Technical Standard for Diagnostic Procedures Using Radiopharmaceuticals](#) [2] and the [ACR Practice Parameter for Continuing Medical Education \(CME\)](#) [9].

Continuing medical education

The physician's continuing medical education should be in accordance with the [ACR Practice Parameter for Continuing Medical Education \(CME\)](#) [9], which requires 150 hours of approved education every 3 years and should include CME in cardiac PET/CT as appropriate to the physician's practice needs.

³ Documented equivalent supervised experience is defined as supervision at a center where the proctoring physician meets these criteria to independently interpret cardiac PET/CT.

B. Qualified Medical Physicist

For Qualified Medical Physicist qualifications, see the [ACR–AAPM Technical Standard for Medical Physics Performance Monitoring of PET/CT Imaging Equipment](#) [10].

C. Radiologic and Nuclear Medicine Technologist

See the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [11] and the ACR–SPR Technical Standard for Diagnostic Procedures Using Radiopharmaceuticals [2].

The Nuclear Medicine Technology Certification Board (NMTCB) has developed a PET specialty examination that is open to appropriately educated and trained, certified, or registered nuclear medicine technologists, registered radiologic technologists, CT technologists, and registered radiation therapists, as specified on the NMTCB website (www.nmtcb.org). The American Registry of Radiologic Technologists (ARRT) offers a CT certification examination for qualified radiologic technologists and allows certified or registered nuclear medicine technologists who meet the educational and training requirements to sit for this examination. Eligibility criteria may be found on the ARRT website (<http://www.arrt.org>).

Certified nuclear medicine and diagnostic CT technologists must follow all applicable state regulations.

D. Radiation Safety Officer

The radiation safety officer must meet applicable requirements of the Nuclear Regulatory Commission (NRC) for training, as specified in 10 CFR 35.50 or equivalent agreement state regulations.

IV. SPECIFICATIONS OF THE EXAMINATION

A. Imaging Protocols

1. Myocardial perfusion imaging

a. Background

Positron emission tomography – computed tomography (PET/CT) scans are performed at rest or with pharmacological stress for noninvasive imaging of the perfusion of the heart for the diagnosis and management of patients with known or suspected coronary artery disease. Rubidium-82 chloride and nitrogen-13 ammonia are the most common PET/CT radiopharmaceuticals for MPI, and fluorine-18-2-fluoro-2-deoxy-D-glucose (FDG) is the standard for myocardial metabolic imaging. Rubidium-82 chloride and nitrogen-13 ammonia are actively transported across the myocardial cell membrane to become trapped within the myocyte. Compared to freely diffusible oxygen-15 water, which has an extraction fraction of 100% during normal and high coronary flow states, both rubidium-82 chloride and nitrogen-13 ammonia are incompletely extracted (ie, <100%) and their extraction further decreases in a nonlinear relationship as myocardial blood flow increases. The baseline first-pass extraction fractions in a normal blood flow state for nitrogen-13 ammonia and rubidium-82 chloride are approximately 80% and 60%, respectively; during a high blood flow state, however, they are approximately 50% and 30%, respectively. Nitrogen-13 ammonia has a half-life of 10 minutes and a short positron range of 0.4 mm, whereas rubidium-82 chloride has a half-life of 76 seconds and a positron range of 2.8 mm, resulting in nitrogen-13 ammonia examinations of better image quality, spatial resolution, and accuracy. However, rubidium-82 chloride is generator produced, whereas nitrogen-13 ammonia is cyclotron produced, leading to greater workflow efficiency and clinical utilization compared to nitrogen-13 ammonia.

b. Patient preparation

Prior to the cardiac PET/CT, the qualified supervising physician should review the indications for the examination, confirm patient hemodynamic stability, review medications, and aim to identify potential risks and contraindications. Contraindications may include pregnancy, allergic reactions to radiopharmaceuticals, and potential adverse responses to administered pharmacologic stress agents.

Patients should abstain from caffeine for at least 12 hours and fast for 4 hours prior to the examination. Patients undergoing myocardial perfusion stress-rest imaging should withhold beta-blockers (if possible), dipyridamole, and caffeine-containing medications. If cardiac PET/CT is performed without a coronary CTA, a small-gauge intravenous (IV) catheter is placed; if a coronary CTA will be performed, a larger-gauge IV catheter is required.

c. Pharmacologic stress

The heart may be stressed using one of a variety of pharmaceutical medications (eg, dipyridamole, adenosine, regadenoson, or dobutamine). 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 to 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 heart block are at increased risk for complications of dipyridamole administration, and these conditions should be considered relative contraindications to use of the medication. As with physical stress, clinical, blood pressure, and electrocardiographic monitoring are mandatory during the dipyridamole infusion and for a period of time following the infusion.
- ii. Adenosine may also be given intravenously in a 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 to 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. Hemodynamic, electrocardiographic, 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. It should not be administered to patients with a second-degree or third-degree atrioventricular block or sinus node dysfunction who do not have a functioning artificial pacemaker.
- iv. Both dipyridamole and adenosine can be combined with simultaneous low-level exercise in patients who are ambulatory to reduce the side effects of these agents, reduce subdiaphragmatic radiopharmaceutical uptake, and improve image quality. While using dipyridamole, exercise should start after the completion of dipyridamole infusion and should last 4 to 6 minutes. While using adenosine, exercise should be simultaneous with the adenosine infusion. Its duration of effect is short (biologic half-life of approximately 2 minutes). Low-level exercise such as the first 2 stages of the modified Bruce protocol suffices.

- 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 mcg/kg/min each step, with a maximum dosage rate of 40 mcg/kg/min. Atropine may be needed to achieve the target heart rate. The end point is 85% of the MPHR (maximum predicted heart rate) or side effects similar to those listed above (section IV.A.1.c.i). Beta-blockers and calcium channel blockers must be withdrawn far enough in advance of the test to eliminate their effect. Dobutamine stress is an alternative in patients who have obstructive pulmonary disease. Dobutamine is associated with an increased incidence of cardiac arrhythmia and should be given with extreme caution in patients prone to arrhythmias or in the post-myocardial infarction period.
- d. Data acquisition
- The patient should be positioned supine on the PET/CT scanner bed with arms raised and supported at or above shoulder level. When not feasible to position the arms out of the imaging field of view, they should be secured by the patient's side to minimize the likelihood of movement between the CT and PET acquisitions. An x-ray scout image should be used to set the scan range to a single PET field of view centered over the heart. Attenuation-correction CT (see section IV.B.1) can be performed either before or after the first PET acquisition. Rest and stress examinations should be performed sequentially, in either order. To minimize interference of the second scan (eg, rest) by activity from the first scan (eg, stress), the time between the 2 administrations is usually at least 4 radionuclide half-lives. If the patient leaves the scanner bed between the rest and stress acquisitions or if patient motion is suspected, the attenuation-correction CT should be repeated.

Except for the pharmacologic stress, PET data acquisition for the rest and stress components of the examination should be identical. The patient should be positioned such that the heart is centered in the PET field of view prior to radiopharmaceutical administration. The administered activity depends on the PET acquisition mode (2-D or 3-D) and may be adjusted according to patient weight/size. For rubidium-82 chloride, 1480 to 2220 MBq (40 to 60 mCi) is administered for 2-D acquisition and 370 to 740 MBq (10 to 20 mCi) for 3-D acquisition. For nitrogen-13 ammonia, 370 to 740 MBq (10 to 20 mCi) is used for 2-D or 3-D acquisition. Note these administered activities apply to either the rest or stress portions of the examination and the total activity will double for a typical examination comprising both components. Consistent administration technique is important, particularly for coronary flow reserve quantification. Rubidium-82 is infused directly from the generator at a rate that is dependent on the system capabilities and age of the generator. For nitrogen-13 ammonia, administration can be as a manual bolus injection or <30-second infusion using a syringe pump, both followed by a saline flush.

If coronary flow reserve quantification is required, PET data should be acquired as a dynamic scan starting at the time of radiopharmaceutical administration. Otherwise, acquisition should commence 1 to 2 minutes after administration for rubidium-82 and 1.5 to 3 minutes for nitrogen-13 ammonia in order to allow for blood pool clearance. Image data are generally acquired for 3 to 7 minutes for rubidium-82 and 10 to 15 minutes for nitrogen-13 ammonia. All PET data should be acquired in conjunction with electrocardiogram (ECG) gating, ideally in list mode to allow flexible reformatting of the data, eg, reconstruction of dynamic, gated, and static images from a single acquisition. Image reconstruction algorithms and equipment performance vary substantially between PET/CT systems and parameters should be carefully optimized for individual systems. In general, iterative reconstruction, with or without time-of-flight information, and pixel sizes between 2 to 4 mm are commonly used. The same reconstruction parameters should be used for rest and stress studies to enable direct image comparison. All usual corrections should be applied to the data, including corrections for randoms, dead time, attenuation, scatter, and normalization. Patient motion between CT and PET should be assessed visually, and additional PET reconstructions incorporating realigned CT data may be obtained as needed.

2. Myocardial Viability Imaging

a. Background

Normal myocardium uses 2 main sources of energy: free fatty acids and glucose. Ischemic myocardium utilizes glucose as an energy source and consumes it at a higher rate than does normal myocardium. The purpose of a viability scan is to identify ischemic but viable tissue in a patient who has apparent scar on SPECT MPI, which might instead represent chronic ischemia at rest. Ischemic regions show a mismatch, that is, higher FDG activity compared to perfusion imaging, indicating the presence of viable tissue that may benefit from restored perfusion.

b. Patient preparation

To optimize myocardial uptake of F-18 FDG in abnormal myocytes, several preparatory steps are required. Most commonly, the patient is instructed to fast for 6 to 12 hours prior to the examination. Prior to infusing F-18 FDG, the patient may be placed on an oral or IV glucose and insulin protocol. The patient may be instructed to ingest a high-fat diet 12 to 24 hours prior to the examination. For diabetic patients, alternative strategies of a euglycemic hyperinsulinemia clamp protocol or administration of nicotinic acid may be considered [12].

c. Data acquisition

The administered FDG activity depends on the PET acquisition mode (2-D or 3-D) and may be adjusted according to patient weight/size. An activity of 370 to 555 MBq (10 to 15 mCi) is administered for 2-D acquisition and at 185 to 370 MBq (5 to 10 mCi) for 3-D acquisition. The target PET start time should be 45 to 60 minutes after FDG injection for nondiabetic patients and 60 to 90 minutes for diabetic patients. The patient should be positioned supine on the scanner bed with arms raised and supported at or above shoulder level. When not feasible to hold the arms out of the imaging field of view, the arms should be secured by the patient's side to minimize the likelihood of movement between the CT and PET acquisitions. An x-ray scout image should be used to set the scan range to a single PET field of view centered over the heart. Attenuation-correction CT (see section IV.B.1) would typically be performed prior to PET data acquisition, although CT after the PET is possible and may be required if substantial patient motion occurs. Positron emission tomography (PET) data are generally acquired as an ECG-gated acquisition for between 10 to 30 minutes. Image reconstruction algorithms and equipment performance vary substantially between PET/CT systems and parameters should be carefully optimized for individual systems. In general, iterative reconstruction, with or without time-of-flight information, and pixel sizes between 2 to 4 mm are commonly used. All usual corrections should be applied to the data, including corrections for randoms, dead time, attenuation, scatter, and normalization. Patient motion between CT and PET should be assessed visually, and additional PET reconstructions incorporating realigned CT data may be obtained as needed.

3. Myocardial/Sarcoid Imaging

a. Background

Cardiac sarcoidosis is an infiltrative disease that usually affects the conduction system. Patients can present with various degrees of heart block or tachyarrhythmias and are at risk for sudden death. Clinically evident cardiac involvement is seen in approximately 5% of patients [13]. The recorded incidence at autopsy ranges between 20% to 25% [14]. F-18 FDG-PET has the benefit of very high sensitivity in evaluation of cardiac sarcoidosis [15,16] with focal intense F-18 FDG uptake. F-18 FDG-PET/CT can accurately diagnose cardiac sarcoidosis, provided there is meticulous patient preparation [17]. Reduction or disappearance of focal F-18 FDG uptake correlates with treatment response [16,17]. Cardiac F-18 FDG-PET/CT and MRI together can provide optimal diagnosis of cardiac sarcoidosis by differentiating between granulomatous inflammation and fibrous changes. F-18

FDG-PET/CT has been shown to be useful for the demonstration of extracardiac sarcoid involvement as well [18,19].

b. Patient preparation

Various dietary regimens are available to achieve suppression of normal glucose utilization by the myocardium. The principle is a high-fat/low-carbohydrate diet the day prior to the PET/CT examination along with 12 to 18 hours of fasting (no gum, candy, or cough drops [20]) and/or use of intravenous heparin (15 to 50 units/kg) about 15 minutes before F-18 FDG injection [21,22]. Inadequate dietary preparation can lead to a false positive or a nondiagnostic examination. The blood glucose level needs to be measured before the F-18 FDG injection and ideally should be below 150 mg/dL.

c. Data acquisition

A rest MPI examination (SPECT or PET, preferably a gated scan) is performed first and reconstructed images should be available for comparison. After the intravenous administration of F-18 FDG at 370 to 555 MBq (10 to 15 mCi) and a 60-minute uptake period, PET images are acquired in a static mode. The cardiac F-18 FDG images are reconstructed and compared to the rest SPECT or PET MPI. Given that sarcoidosis is a systemic disease, conventional whole-body F-18 FDG-PET/CT imaging may be performed from the cerebellum to the mid thighs to evaluate F-18 FDG uptake in extracardiac regions.

B. Other Examination Specifications

1. Attenuation correction (AC)

Attenuation correction of PET images is required and can be achieved with germanium rod sources or CT. (Use of MRI for AC is an evolving practice, and guidelines for use of MRI for attenuation correction of PET data are outside the scope of this practice parameter.) Computed tomography (CT) attenuation correction (CTAC) data can be obtained prior to, during, or after a PET scan on the same scanner. Generating a separate CTAC for each PET/CT imaging session performed (ie, if the patient gets off the scanner between imaging sessions) is recommended to achieve best anatomic positioning and avoid artifacts. If rest and stress imaging are performed without moving the patient, only 1 CTAC image is required. CT can be performed by a variety of methods, but regardless of the method, a careful review of the CT images for incidental findings and reporting of these findings is required.

It is important to register the proper position of the mediastinal structures on CTAC and PET, which are affected by respiratory motion, cardiac motion, and gross patient movement. This can be achieved by one or more of a variety of methods. Inaccurate co-localization of the CTAC to non-attenuation-corrected (NAC) PET data can result in artifacts on the attenuation-corrected (AC) PET images [23-25]. The CT can be acquired during shallow breathing or with a breath hold at end-tidal volume. Subsequent PET data should be obtained during shallow breathing, as PET acquisition time is longer than CT. The NAC and AC PET images must be visually inspected for proper coregistration of radiopharmaceuticals on NAC PET to the myocardial anatomy on CT.

It is generally recommended to use a low-dose CT technique for CTAC. However, when indicated, CT can be performed for diagnostic purposes, including higher-dose CT protocol, IV contrast, cardiac gating, and/or full-inspiration breath-hold techniques. High concentration of IV contrast can cause attenuation-correction artifacts on PET images, and caution is recommended if these images are to be used for CTAC [26-30]. Full breath-hold CT can cause artifacts as registering of anatomy on CTAC and NAC PET can be difficult. It is acceptable to perform a low-dose CTAC scan in addition to an indicated diagnostic CT scan. For further details on CTAC of PET, please see the [ACR-SPR Practice Parameter for Performing FDG-PET/CT in Oncology](#) [31].

Although diagnostic CT acquired at the same scanning session as the PET can potentially be used for attenuation correction, an additional low-dose CT is recommended to reduce image registration complications. Computed tomography for attenuation correction should be acquired at end expiration or shallow free breathing to minimize misalignment between the PET and the CT. The gantry rotation speed is usually slow (1 s/revolution or slower) in order to blur cardiac motion and better match the PET. As diagnostic image quality is not required, the tube current should be low (50 mA or lower) and neither contrast material nor ECG gating should be used. For perfusion PET studies, a single CT may be adequate to correct both rest and stress PET data if the patient did not move significantly between the 2 acquisitions. Two separate CT scans will be needed if the patient moves between the rest and stress portions of the test. Registration between the PET and CT data should be visually assessed and manual or computer-optimized realignment performed as required.

2. Quantification of absolute myocardial blood flow

Absolute myocardial blood flow (MBF) can be assessed quantitatively by cardiac PET/CT. MBF results in an estimated absolute rate of blood flow to the myocardium, as opposed to a comparative measure where at least a portion of the myocardium is considered “normal” and the diseased myocardium is compared to the patient’s own myocardium as a normal control. PET is uniquely well suited to calculate MBF. When comparing stress and rest MBF, the myocardial flow reserve (MFR) can be calculated. Flow reserve contributes additional information to MPI in terms of predicting prognosis and risk stratification [32,33].

Dynamic imaging initiated at the time of injection is required for MBF quantification. List-mode acquisition of PET data allows for reconstruction of the PET data over time and accurate calculation of MBF. A region of interest (ROI) is placed on the aorta (or other structure representing arterial flow) and on the myocardium (including volumes representing each vascular territory) to generate image-derived time-activity curves that are used in conjunction with kinetic models. The kinetic model estimates the MBF as rate of uptake into the myocardium in terms of mL/min/g. MFR is then calculated as the ratio of MBF at peak hyperemia over the MBF during rest. For routine clinical calculation of the MBF and MFR, the use of an automated, validated, and FDA (Food and Drug Administration)–approved analysis tool is recommended [34].

Three-dimensional PET requires adapted methods, including a possible reduction in administered activity, for the calculation of MBF compared to 2-D data acquisition [35,36]. Care must be given to not allow the radiopharmaceutical activity in the bolus during first-pass imaging to exceed the range of accurate detection of the camera, which can be particularly difficult when using 3-D data acquisition.

3. Coronary calcium scoring

Coronary calcium scoring may be performed in conjunction with cardiac PET/CT perfusion imaging. Generally, a separate CT acquisition complements the CT used for attenuation correction of the PET data, although a single acquisition may be feasible. The CT component of the PET/CT hybrid instrumentation should meet the minimal requirements of a 16-slice scanner with a rotational speed of 0.5 s/rotation. More slices and faster speeds are preferable. Image acquisition should be during a single breath hold, with the images gated to 60% to 80% of the R-R interval. Radiation exposure should be as low as possible, while still-acceptable settings for Agatston score, by using tailored protocols based on patients’ body mass index (BMI), as well as other dose-reduction strategies, which may be manufacturer specific.

Software is available to calculate the calcium score from all manufacturers and third-party vendors. Most commonly used is the Agatston score, although mass or volume scores may also be obtained. The primary advantage of the Agatston score [37] is the large number of published studies and the availability of large databases to aid in interpretation of the results. The Multi-Ethnic Study of Atherosclerosis (MESA) database, available online, can be used to calculate percentile comparisons that are corrected for age, gender, and ethnicity. The MESA Calcium Calculator can be found at <http://mesa-nhlbi.org/Calcium/input.aspx>. When reporting the calcium score the appropriate percentile should be

included, although it should be noted that the databases are derived from asymptomatic subjects, and in patients with known coronary artery disease (CAD), the use of the MESA database is not indicated.

4. For more specific details on coronary CTA, please refer to the [ACR–NASCI–SIR–SPR Practice Parameter for the Performance and Interpretation of Body Computed Tomography Angiography \(CTA\)](#) [38].

V. EQUIPMENT SPECIFICATIONS

A. General Requirements

In addition to a clinical PET/CT system with the capabilities noted below, the following auxiliary equipment may also be required. Use of rubidium-82 chloride will require a generator system that can be positioned adjacent to the scanner, allowing direct infusion to the patient; a radionuclide activity calibrator (dose calibrator) is needed to assay radiopharmaceuticals and perform quality assurance on rubidium-82 chloride generators; a syringe pump can optionally be used for PET radiopharmaceutical administration; an electrocardiogram integrated with the PET/CT system is required to allow ECG-gated image acquisition; for CTA studies, a dual power injector is required for the controlled administration of iodinated contrast material and normal saline; dedicated software for the display and quantitative analysis of cardiac PET and CT images is also necessary. In addition, it is important to maintain specific emergency medical equipment in the scanner room, such as defibrillators, intubation gear, cardiopulmonary resuscitation first aid equipment, a contrast reaction kit, and emergency drugs.

B. PET (Positron Emission Tomography) Requirements

Current clinical PET/CT systems generally have a PET field of view that is sufficiently large (at least 15 cm) to allow the entire heart to be imaged without the need for bed translation. PET systems based on lutetium oxyorthosilicate, lutetium yttrium orthosilicate, bismuth germinate, and gadolinium oxyorthosilicate are all acceptable. Both 2-D (septa-in) and 3-D (septa-out) data acquisition are suitable. The ability to acquire PET data in conjunction with ECG gating is needed (typically at least 8 gates) and the use of simultaneous respiratory gating can also be employed when available. When quantification of coronary flow reserve is to be performed, list-mode data acquisition is preferred as it allows dynamic, ECG-gated, and static images to be reconstructed from a single acquisition. Image reconstruction can be performed with either analytical or iterative algorithms, although the same reconstruction protocol should be used when comparing studies such as those acquired at rest and stress. All usual quantitative corrections should be applied to the data, including normalization, randoms, attenuation, scatter, dead time, and decay corrections. Time-of-flight information should be used when available. The role of image reconstruction with resolution recovery (point spread function modeling) has not yet been established. Image analysis requires dedicated software for realignment to the conventional cardiac orientation, convenient side-by-side presentation of related series (eg, rest and stress images), and cine display of ECG-gated images. Quantitative analysis, including measurement of ejection fraction and coronary flow reserve, requires additional software capabilities. The ability to override automatic segmentation of the myocardial walls and manually positioned constraints is an important requirement.

C. Computed Tomography (CT) Requirements

Computed tomography requirements vary depending on the intended applications. CT for attenuation correction can be performed on all clinical PET/CT systems that incorporate diagnostic multidetector CT, irrespective of the slice configuration. Electrocardiogram gating is not required. The PET/CT console should have tools to allow registration of PET and CT cardiac images and a mechanism to incorporate the resulting motion parameters into a new attenuation-corrected PET reconstruction based on the aligned CT. Calcium-scoring CT typically employs an ECG-triggered axial scan mode, so CT systems with large detectors are preferred in order to minimize the time required for breath holding; 16-slice CT systems capable of 0.5

s/revolution are required as a minimum. Coronary CTA requires substantially more advanced multidetector CT capability. At least 64-slice CT with 0.5 s/revolution or less is recommended. Cardiac motion is mitigated either by prospective ECG triggering or by retrospective ECG gating. A power injector is required for the controlled administration of iodinated contrast material and the scanner needs to support a method for determining the contrast arrival time for optimal arterial enhancement. Dedicated software is required to review coronary CTA studies and also to quantify calcium-scoring CT.

D. Quality Control Requirements

Technical standards for quality control of PET/CT systems have been described in the [ACR–AAPM Technical Standard for Medical Physics Performance Monitoring of PET/CT Imaging Equipment](#) [10]. These recommendations incorporate the standards for CT (see the [ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography \(CT\) Equipment](#) [39]), which are particularly important for cardiac applications. Although radiopharmaceutical quality control is beyond the scope of this document, quality control for rubidium-82 chloride generators deserves mention as it is typically the responsibility of the imaging staff, as opposed to a radiopharmacist. Quality control of rubidium-82 chloride generators should be performed daily, prior to patient administrations, and should include measurement of the levels of strontium-82 and strontium-85 in the rubidium-82 chloride injection.

VI. DOCUMENTATION

Reporting should be in accordance with the [ACR–AAPM Practice Parameter for Communication of Diagnostic Imaging Findings](#) [5].

If stress testing is part of cardiac PET/CT examination, the interpretation of findings from the stress test should be reported.

VII. RADIATION SAFETY

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)

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’s [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).

VIII. 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 (<http://www.acr.org/guidelines>).

Equipment performance monitoring should be in accordance with the [ACR–AAPM Technical Standard for Medical Physics Performance Monitoring of PET/CT Imaging Equipment](#) [10].

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 web site (<http://www.acr.org/guidelines>) by the Committee on Practice Parameters and Technical Standards – Nuclear Medicine and Molecular Imaging of the ACR Commission on Nuclear Medicine and Molecular Imaging, the Committee on Body Imaging (Cardiovascular) of the ACR Commission on Body Imaging, and the Committee on Practice Parameters – Pediatric Radiology of the ACR Commission on Pediatric Radiology in collaboration with the SPR, and the STR.

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