SPECT: Single Photon-Emission Computed Tomography

SPECT Instrumentation and Quality Assurance

OVERVIEW

The proper choice of equipment to acquire clinical data and a well-designed quality assurance (QA) program are both essential to optimize diagnostic accuracy and ensure consistent, high-quality imaging. This document will cover the minimum requirements needed for a single photon-emission computed tomography (SPECT) camera in cardiac imaging as well as the different QA procedures.

MINIMUM SPECT CAMERA REQUIREMENTS

SPECT camera designs are based on a number of fundamental components, all of which play an integral role in the system performance and choice of a SPECT system.

Detector type: Detector types include scintillation cameras (i.e., Anger), solid-state, pixilated scintillation crystals, and semiconductor/solid-state detectors.

Energy resolution: Energy resolution is an important determinant of image quality. The energy window needs to be adjusted for technetium or thallium. It can be improved with solid-state detector technology.

Spatial Resolution: Spatial resolution is mainly affected by the collimator in Anger camera designs. The image reconstruction algorithm and filtering also affect the final resolution.

Collimators: The collimator is the most important component of the SPECT system for determining image quality. The width and depth of the collimator septa control the trade-offs between sensitivity and resolution. Low-energy, high-resolution (generally preferred with Tc-99m-based agents) collimators and low-energy, all-purpose (generally preferred for Tl-201) collimators are most commonly used. Parallel-hole collimation is most often used in Anger cameras. The use of newer reconstruction algorithms, the dose and type of radionuclide, the patient population tested, and collimator choice will vary among laboratories.

Table 1. **Various SPECT cameras used in cardiac imaging**

Camera Design	Comments
Single-head camera	No longer widely used for cardiac applications
Dual-head camera	180 degree orbit, 90 degree separation of detectors for cardiac application. Camera heads with acute angle configurations and longer scan range may prevent truncation artifacts.
Triple-head camera	Higher sensitivity for cardiac applications, but greater image noise.
Non-standard camera	Generally, smaller field of view cameras with fixed 90 degree configuration. Reduced weight and space requirements. Patient positioning may be reclined or horizontal. May not have visible moving components. Some systems have the patient rotating in an upright chair with a stationary scanner.

SPECT CAMERA QUALITY ASSURANCE

One of the essential requirements for ensuring consistent, high-quality diagnostic SPECT imaging is a well-designed, multi-component QA program. The general components of quality control (QC) procedures are shown in Table 2.

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Practice Points

Table 2. **Summary of Nuclear Cardiology QC Procedures**

Test	Priority	Frequency	TYPE OF SYSTEM		
			SPECT	SPECT /TCT	SPECT/CT
Acceptance testing per NEMA	Recommended	Upon delivery, major hardware upgrades	✓	✓	✓
Energy peaking	Mandatory	Daily	✓	✓	✓
Uniformity test	Mandatory	Daily	✓	✓*	✓
Transmission Source Mechanics	Mandatory	Daily*		✓	
Water phantom QA	Recommended	Daily*		✓	✓
Tube warm-up	Recommended	Daily*			✓
Air calibration (“fast QA”)	Recommended	Daily*			✓
Source Strength	Mandatory	Monthly*		✓	
Calibration	Mandatory	Monthly*			✓
Field Uniformity	Mandatory	Monthly*			✓
Water phantom checks: slice thickness, accuracy, positioning	Recommended	Monthly*			✓
Total Performance	Recommended	Quarterly	✓	✓	✓
Resolution and linearity	Recommended	Manufacturer’s recommendation	✓	✓	✓
Sensitivity	Optional	Manufacturer’s recommendation	✓	✓	✓
Center-of-Rotation Multidetector Registration	Mandatory	Manufacturer’s recommendation	✓	✓	✓
Uniformity Calibration	Mandatory	Manufacturer’s recommendation	✓	✓	✓

* or as recommended by the manufacturer; TCT - transmission computed tomography;
NEMA - National Electrical Manufacturers Association standards publication NU 1-2007

The optimal way in which to perform specific QA tests varies considerably between models of imaging equipment and this document is not intended to replace manufacturers' recommendations. However, if the manufacturer does not provide an equivalent test or indicate the frequency of when these tests should be performed as outlined in this section, the existing guideline protocols and frequencies should be enforced.

Here are definitions of the major QA measures shown in Table 2:

Acceptance testing: It is recommended that the NEMA (National Electrical Manufacturers Association) performance measurements (NU 1-2007) be made before accepting the SPECT scanner. Many of these tests will be performed by the company supplying the SPECT scanner.

Energy peaking: Energy peaking is performed in order to verify that the camera is counting photons with the correct energy. This test requires either the manual or automatic placement of the correct pulse height analyzer's energy window over the photopeak energy to be used.

Uniformity test: A uniformity test is performed in order to verify that the camera's sensitivity response is uniform across the detector's face. Two methods of performing this test are 1) intrinsic (i.e., using a point source without collimators) or 2) extrinsic (i.e., with the collimator in place in conjunction with a sheet source, usually of Co-57).

Resolution and linearity test: This test is performed in order to document spatial resolution and its change over time, as well as the detector's ability to image straight lines. The test consists of imaging a flood source intrinsically through a spatial resolution test phantom.

Center-of-rotation (COR) calibration: An alignment error between the center of the electronic matrix of the camera and the mechanical COR can potentially result in a characteristic "doughnut" (if a 360 degree orbit and a point source are used) or "tuning fork" artifact (if a 180 degree orbit is used) in the transverse images. The effects are most evident when the error is greater than two pixels in a 64 x 64 matrix. Errors less than this reduce spatial resolution.

WHEN TO REPEAT THE SPECT SCAN ACQUISITION

Factors leading to a decision to either delay or abort SPECT imaging include camera-related factors as well as patient-related factors. Camera-related factors may include malfunctioning due to:

- Analyzer peaking
- Uniformity floods
- Sensitivity and resolution
- COR

If any of these factors are not within an acceptable range, SPECT imaging should not commence, and the Field

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Service Engineer (FSE) should be notified. Imaging should not restart until the FSE has thoroughly examined the camera system and all QC has been repeated and is within acceptable limits. Patient-related factors may include:

- Patient breathing/motion artifacts
- Liver uptake
- Bowel uptake
- Body habitus
- Acute changes in the patient's clinical condition requiring acute intervention (e.g., hemodynamic instability, extreme brady- or tachyarrhythmia, mental status changes, severe chest pain, etc.)

In the presence of significant patient breathing/motion artifacts, SPECT imaging should be aborted until the patient has had enough time post-injection to allow for his or her breathing to return to normal. The patient should also be instructed not to move his or her arms, legs, and shoulders during imaging; the image is repeated once the patient has had enough time to settle. In the presence of significant liver uptake and bowel uptake that could preclude interpretation, SPECT imaging should be aborted until there has been sufficient time for liver clearance and for the bowel uptake to have moved far enough away from the cardiac silhouette to begin imaging.

SUGGESTED READING

Holly TA, Abbott BA, Al-Mallah M, et al. ASNC imaging guidelines for nuclear cardiology procedures: Single photon-emission computed tomography. J Nucl Cardiol 2010;17:doi: 10.1007/s12350-010-9246-y.

National Electrical Manufacturers Association. NEMA Standards Publication NU 1-2007: Performance measurements of scintillation cameras. Washington, DC: National Electrical Manufacturers Association; 2007.

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SPECT Acquisition

OVERVIEW

The implementation of ASNC-suggested acquisition protocol parameters is essential in order to provide acceptable, quality images for routine clinical interpretation and quantification. In addition, newer protocol parameters (other than those listed below) that reduce imaging time or allow for the use of reduced doses of radiopharmaceuticals have been recently suggested and validated in smaller, single-center studies and thus may be preferred at some institutions.

TECHNETIUM-BASED PROTOCOLS

Protocols for the various nuclear cardiology single photon-emission computed tomography (SPECT) acquisition studies using Anger camera technology and conventional filtered backprojection reconstruction are presented in Tables 1 - 3 as well as in Figure 1. Stress tests should be performed as per the *ASNC Imaging Guidelines for Nuclear Cardiology Procedures.*

Table 1. **Patient protocol: Tc-99m acquisitions**

	Same-day Rest-Stress Tc-99m acquisition		Same-day Stress-Rest Tc-99m acquisition		Two-day Stress Tc-99m acquisition	
	Rest	Stress	Stress	Rest	Stress	Rest
Dose	8-12 mCi#	24-36 mCi#	8-12 mCi#	24-36 mCi#	24-36 mCi#	24-36 mCi#
Position	• Supine • Prone* • Upright/ semi-upright*	• Supine • Prone* • Upright/ semi-upright*	• Supine • Prone* • Upright/ semi-upright*	• Supine • Prone* • Upright/ semi-upright*	• Supine • Prone* • Upright/ semi-upright*	• Supine • Prone* • Upright/ semi-upright*
Delay time (intervals) Injection —> imaging	30-60 min	15-60 min	15-60 min	30-60 min	15-60 min	30-60 min
Injection 1 to injection 2		30 min-4 hr		30 min-4 hr		N/A

Doses may be adjusted upward for heavier patients by 0.31 mCi/kg for Tc-99m; *alternative

THALLIUM-BASED PROTOCOLS

Thallium-based protocols are shown in Figure 2. The standard dose for thallium-based protocols is 2.5 - 3.5 mCi Tl-201. Doses may be adjusted upward for heavier patients by 0.04 mCi/kg for Tl-201. For Tl-201 studies, the energy window position is 70 keV and a low-energy all-purpose (LEAP) collimator is usually used. Please note that in comparison to Tc-99m-based imaging, Tl-201 imaging should begin approximately 10 to 15 minutes after stress testing. In addition, the time per projection should be 40 seconds for 32 projections and 25 seconds for 64 projections. Other imaging parameters are the same as technetium.

PRONE IMAGING

Prone imaging is usually used in patients with motion and/or inferior wall attenuation. The combination of supine and prone images may be helpful in identifying attenuation artifacts. Prone imaging does not eliminate

Table 2. **Acquisition protocol**

	Low Dose (8-12 mCi)
Energy window	15-20% symmetric
Collimator	LEHR
Orbit	180° (45° RAO to 45° LPO)
Orbit type	Circular Non-Circular*
Pixel size	6.4 ± 0.4 mm
Acquisition type	Step and shoot Continuous*
Number of projections	60-64
Matrix	64 x 64
Time/projection	25s for low dose (8-12 mCi) and 20s for high dose (24-36 mCi)
ECG gated	Standard
Frames/cycle	8 16*
R-to-R window	100%

* alternative; RAO - right anterior oblique; LPO - left posterior oblique; LEHR - low-energy–high-resolution ; ECG - electrocardiogram

Figure 1A. **Same-day rest-stress Tc-99m**

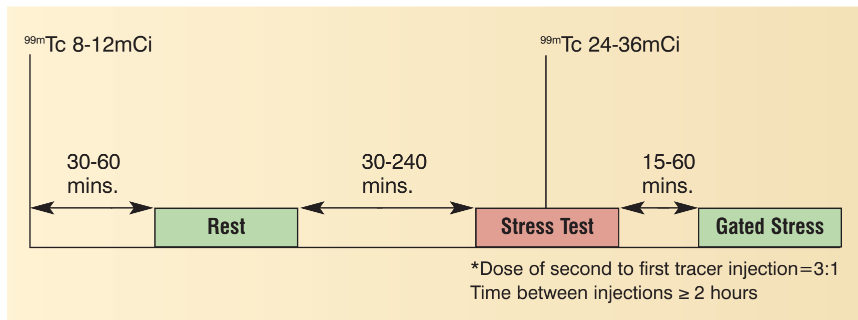


Figure 1B. **Same-day stress-rest Tc-99m**

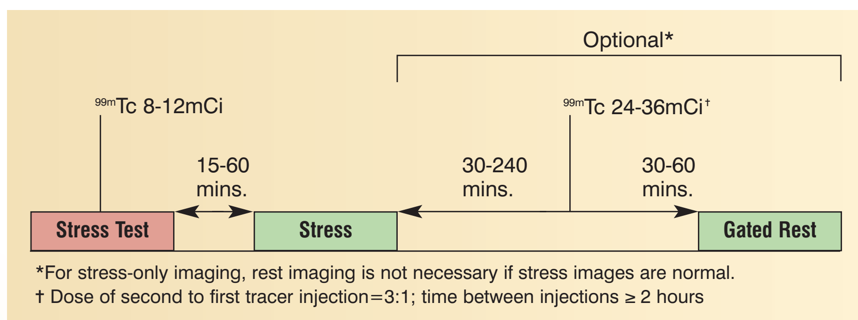
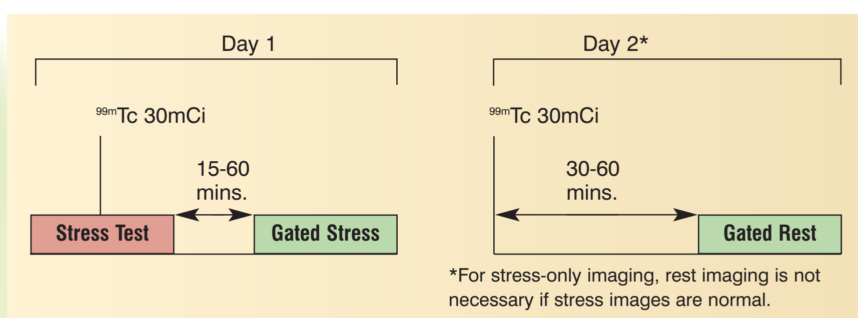


Figure 1C. **Two-day stress Tc-99m**



attenuation artifacts, but rather changes the location. By comparing supine and prone images, artifactual defects will change their location whereas true perfusion defects will remain fixed. It is suggested that prone imaging be performed in combination with supine imaging (rather than replacing it).

GATING

Gating requires a stable and consistent heart rhythm as well as sufficient temporal resolution to correctly characterize the cardiac cycle. Beats that fall more than 20 percent of a stable RR interval are usually rejected. Eight- or 16-frame gating could be used. The *ASNC Imaging Guidelines for Nuclear Cardiology Procedures: Single Photon-Emission Computed Tomography* recommend that both stress and rest SPECT perfusion studies be acquired as gated data sets, provided that there is adequate count density with regard to Tl-201 or lower dose Tc-99m (8-12 mCi) acquisitions.

Figure 2A. **Same-day stress-reinjection-redistribution Tl-201**

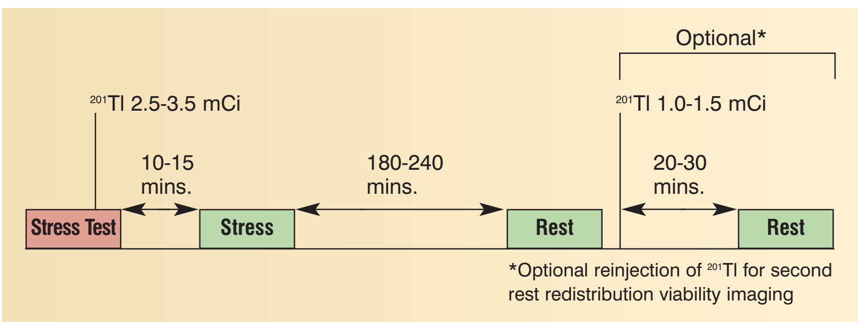
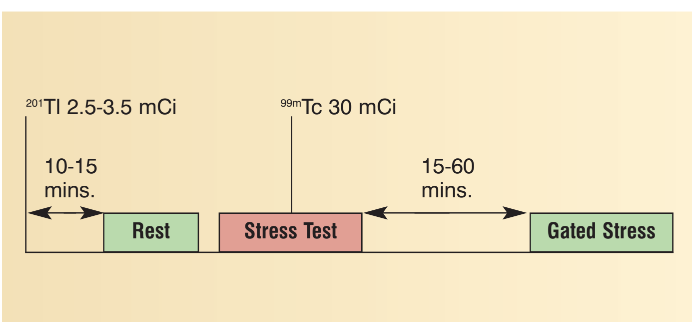


Figure 2B. **Same-day dual-isotope**



IMPROVEMENT OF IMAGE ACQUISITION IN SPECIAL CIRCUMSTANCES

Optimum image quality is desired for all scintigraphic imaging. The quality of myocardial perfusion imaging (MPI) depends on several parameters—some are intrinsic to the body and some are technical and thus extrinsic. Various factors like attenuation, artifacts, sub-optimal counts, etc., degrade the quality of the image. Frequently encountered problems and possible solutions are listed in Table 3 on the following page.

SUGGESTED READING

Holly TA, Abbott BA, Al-Mallah M, et al. ASNC imaging guidelines for nuclear cardiology procedures: Single photon-emission computed tomography. J Nucl Cardiol 2010;17:doi: 10.1007/s12350-010-9246-y.

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Table 3. **Frequently encountered problems during SPECT acquisition**

PROBLEMS	HOW TO AVOID	HOW TO CORRECT
High sub-diaphragmatic counts	• Adequate exercise • Fatty meal • Optimum delay between acquisition (minimum 45 minutes for Sestamibi and 30 minutes for Tetrofosmin)	• Consider prone imaging • Repeat imaging
High stomach counts	• Check labelling • Give carbonated beverages	• Masking of activity • Repeat acquisition after Metoclopramide
Motion	• Proper instruction to the patient • Sufficient delay to recover from the effects of exercise/stress • Cine mode QC	• If motion is more than one pixel, automatic or manual motion correction software to be used • Cross checking of sinogram and linogram • Consider prone imaging
Diaphragmatic attenuation/breast attenuation	• Image the patient in the same position/clothing to avoid shifting breast attenuation	• Consider prone imaging • Attenuation correction by CT
Gating artifacts	• Check for arrhythmia • Proper setting of gating histogram width • Ensure proper voltage of ECG triggers	• Repeat imaging • Change the ECG leads • Discard gating in cases where there is count loss/flashing of cine images

QC – quality control; CT – computed tomography; ECG – electrocardiographic

SPECT Processing and Interpretation

OVERVIEW
In this document, we will review Cardiac SPECT processing and interpretation techniques as recommended by the *ASNC Imaging Guidelines for Nuclear Cardiology Procedures: Single Photon-Emission Computed Tomography.* The implementation of these steps is essential in order to provide relevant clinical interpretation that will aid in the management of patients.

IMAGE PROCESSING
Different processing tools are available for image reconstruction and filtering. The traditional method of image reconstruction has been filtered backprojection, which does not correct for photon attenuation, scatter, or collimator blurring. The application of a ramp filter amplifies the already relatively noisy high-frequency content of the acquired profiles but may result in ramp filter artifact in the presence of an area of increased tracer uptake nearby (e.g., bowel, papillary muscle).

ITERATIVE RECONSTRUCTION
Iterative reconstruction is based upon an initial assumption or guess. The guess is refined based on the differences between the generated and actual projections; the process is then repeated usually for a fixed number of iterations but can also be repeated until the error between the generated and actual projections is acceptably small. The main advantage of iterative reconstruction is that the process of generating projections can incorporate corrections for attenuation, scatter, and collimator-specific, depth-dependent blurring. Disadvantages of iterative reconstruction include the computational intensity of the algorithms involved (requiring advanced computer technology) and the potential to introduce data that is not reflective of the raw images.

FILTERING
- The optimal filter for a given image depends on the signal-to-noise ratio for that image.
- Under-filtering an image leaves significant noise in the image.
- Over-filtering unnecessarily blurs image detail.
- Both over-filtering and under-filtering can reduce image accuracy.

REORIENTATION AND DISPLAY
- Reorientation is performed either manually or automatically, and results in sectioning the data into vertical long-axis, horizontal long-axis, and short-axis planes.
- Long-axis orientation lines should be parallel to long-axis walls of the myocardium and should be consistent between rest and stress studies. Inappropriate plane selections can result in misalignment between rest and stress data sets, potentially resulting in incorrect interpretation.

INTERPRETATION
The interpretation of myocardial perfusion single photon-emission computed tomography (SPECT) images should be a systematic process which routinely includes:

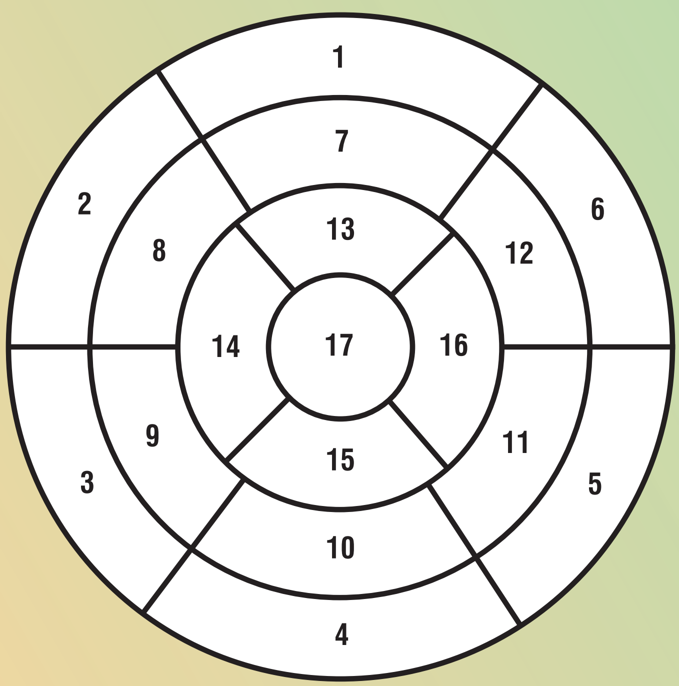
1. An evaluation of the raw tomographic data in cine mode for identifying sources of artifact and extracardiac findings.

2. An evaluation of location, size, severity, and reversibility of perfusion defects; cardiac chamber sizes; and presence or absence of increased pulmonary uptake (for Tl-201).
3. Review and incorporation of quantitative perfusion analysis.
4. An evaluation of gated images for global and regional ventricular function.
5. Review and consideration of clinical factors that may influence the final interpretation of the study.

Figure 1. **SPECT myocardial perfusion imaging: 17-segment model**

SPECT MYOCARDIAL PERFUSION IMAGING

1. basal anterior
2. basal anteroseptal
3. basal inferoseptal
4. basal inferior
5. basal inferolateral
6. basal anterolateral
7. mid anterior
8. mid anteroseptal
9. mid inferoseptal
10. mid inferior
11. mid inferolateral
12. mid anterolateral
13. apical anterior
14. apical septal
15. apical inferior
16. apical lateral
17. apex



DISPLAY

1. It is strongly recommended that the reading physician use images from the computer monitor screen rather than hard copies (e.g., paper or film) to interpret the study.
2. Image normalization is optimally performed with "series normalization," in which the brightest pixel in each series of images (vertical, horizontal, short axis) is normalized to the brightest pixel in the entire image set.
3. Three-dimensional displays may be useful as adjunct to conventional slice displays.

EVALUATION OF THE IMAGES

A review of raw tomographic data in cine mode is essential for detecting sources of artifact (e.g., breast and/or diaphragmatic attenuation, abdominal visceral activity, patient motion). It also may permit the detection of areas of abnormal extracardiac tracer uptake. Intermittent "flashing" of the cine gated images suggests gating error related to arrhythmias.

IMAGE ANALYSIS AND INTERPRETATION

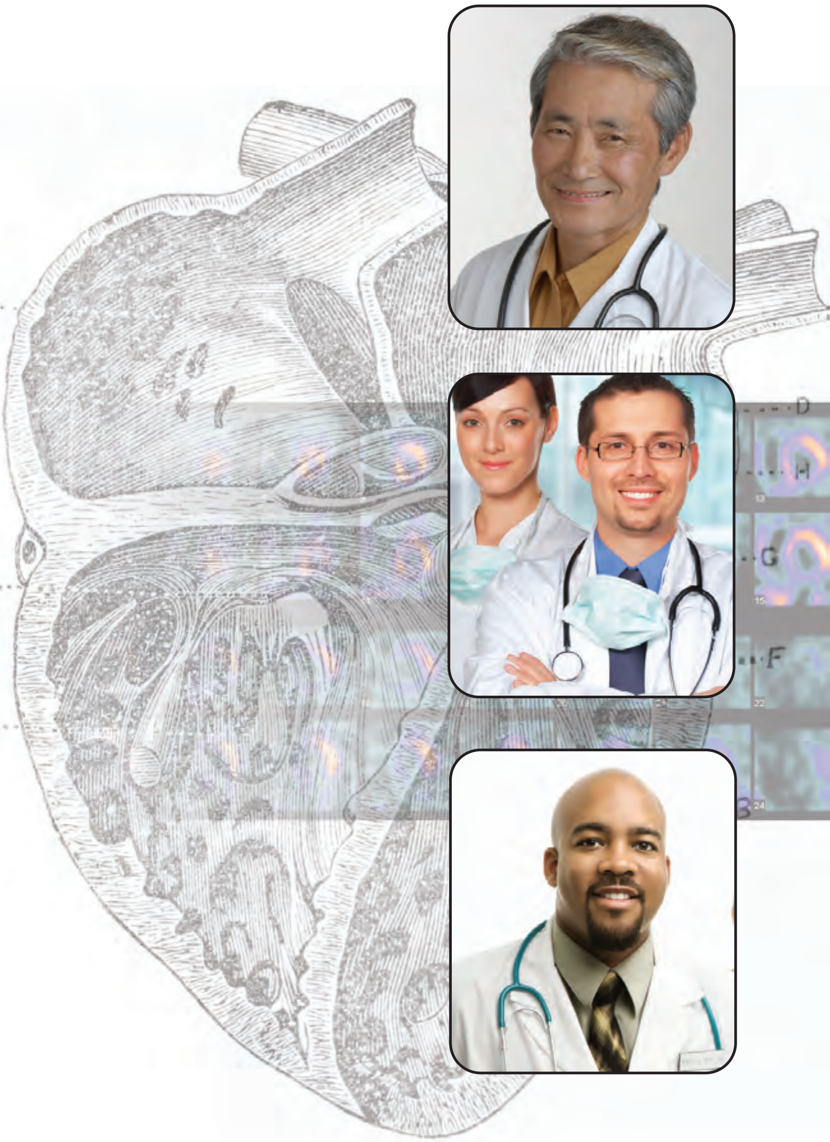
It is recommended that the initial interpretation of the perfusion study be performed without any clinical information other than the patient's gender, height, and weight to minimize bias in study interpretation. All relevant clinical data should be reviewed after a preliminary impression is formed. Each of the following should be assessed in the standard interpretation of all SPECT myocardial perfusion imaging studies:

1. **Ventricular dilation:** Left ventricular (LV) enlargement at rest and/or or post-stress should be noted. Stress-to-rest LV cavity ratio, also referred to as transient cavity dilatation (TCD) or transient ischemic dilation (TID), has been described as a marker for high-risk coronary disease.
2. **Lung uptake:** The presence of increased lung uptake after thallium perfusion imaging is an indicator of poor prognosis and should therefore be routinely evaluated in patients imaged with Tl-201.

Table 1. **The Five-Point Model**

Category	Score
Normal perfusion	0
Mild reduction in counts — not definitely abnormal	1
Moderate reduction in counts — definitely abnormal	2
Severe reduction in counts	3
Absent uptake	4

3. **Right ventricular (RV) uptake and RV dilation:** RV uptake and RV dilation may be qualitatively assessed on the raw projection data and on the reconstructed data. The intensity of the right ventricle is normal approximately 50 percent of peak LV intensity.
4. **Non-cardiac findings:** Both thallium- and technetium-based agents can be concentrated in tumors, and uptake outside the myocardium may reflect unexpected pathology.
5. **Perfusion defects:** Myocardial perfusion defects should be identified by visual analysis of the reconstructed slices. The perfusion defects should be characterized by their location as they relate to specific myocardial walls using the 17-segment model (Figure 1). Defect severity is typically expressed qualitatively as mild, moderate, or severe. Defect extent may be qualitatively described as small, medium, or large. Defects whose severity and extent do not change between stress and rest images are categorized as "fixed" or "nonreversible." When perfusion defects are more severe and/or extensive on stress compared to rest images, a qualitative description of the degree of reversibility is required.
6. **Semiquantitative analysis:** The use of a semiquantitative segmental scoring system standardizes the visual interpretation of scans, reduces the likelihood of overlooking significant defects, and provides an important index that is applicable to diagnostic and prognostic assessments. However, the accuracy of these scores is highly dependent upon how the initial images are setup for processing. The 17-segment, five-point scoring system (Table 1) is recommended. In addition to individual scores, summed stress scores (SSS), summed rest scores (SRS), and summed difference score (SDS) should be calculated. Ischemia on scans is categorized as mild when the SDS is 1 to 3, moderate when the SDS is 4 to 7, or severe when the SDS is greater than 7.
7. **Gated SPECT — regional wall motion and thickening:** Regional wall motion should be analyzed using a standard nomenclature: normal, hypokinesis, akinesis, and dyskinesis. Hypokinesis may be further qualified as



mild, moderate, or severe. A semiquantitative scoring system is recommended where 0 is normal, 1 is mild hypokinesis, 2 is moderate hypokinesis, 3 is severe hypokinesis, 4 is akinesis, and 5 is dyskinesis.

8. **Left ventricular ejection fraction (LVEF) and volume:** Quantitative evaluation of LVEF should be done and reported. LVEF may be categorized as normal, mildly, moderately, or severely reduced. Left ventricle chamber sizes as well as end-diastolic and end-systolic volumes should routinely be evaluated qualitatively and quantitatively.

INTEGRATION OF PERFUSION AND FUNCTION RESULTS

1. The results of the perfusion and gated SPECT data sets should be integrated into a final interpretation.
2. The wall motion is particularly helpful in distinguishing nonreversible (fixed) perfusion defects due to prior myocardial infarction from nonreversible defects due to attenuation artifacts.
3. Fixed perfusion defects that do not show a corresponding abnormality of wall motion or myocardial systolic thickening are more likely to be due to artifacts.

MODIFICATION OF INTERPRETATION BY RELEVANT CLINICAL INFORMATION

- It is important to keep in mind the majority of artifacts encountered will produce mild defects.
- When uncertainty exists, it is helpful to incorporate clinical information (e.g., symptoms, risk factors, ST-segment changes, exercise tolerance) to help the referring physician make the most appropriate management decisions for the patient.
- Markers of severe ischemia, such as marked ST-segment changes, increased stress:rest LV cavity ratio (transient ischemic dilation), or increased lung uptake (particularly with thallium) should be used to identify those patients with balanced ischemia due to multi-vessel coronary artery disease.

REPORTING

A detailed description of SPECT reporting is described in the *ASNC Imaging Guidelines for Nuclear Cardiology Procedures: Reporting of Radionuclide Myocardial Perfusion and Function* as well as the *ASNC Practice Points: Reporting of Myocardial Perfusion Imaging Tests.*

SUGGESTED READING

Holly TA, Abbott BA, Al-Mallah M, et al. ASNC imaging guidelines for nuclear cardiology procedures: Single photon-emission computed tomography. J Nucl Cardiol 2010;17:doi: 10.1007/s12350-010-9246-y.

Tilkemeier PL, Cooke CD, Grossman GB, et al. ASNC imaging guidelines for nuclear cardiology procedures: Standardized reporting of radionuclide myocardial perfusion and function. J Nucl Cardiol 2009;16:doi: 10.1007/s12350-009-9095-8.

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