ASNC IMAGING GUIDELINES FOR NUCLEAR CARDIOLOGY PROCEDURES

First-pass radionuclide angiography

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ACQUISITION PARAMETERS

Purpose. To assess left ventricular (LV) and right ventricular (RV) function at rest or during stress (evaluation of wall motion, ejection fraction [EF], and other systolic and diastolic parameters). To assess and measure left-to-right shunts (Table 1).

ACQUISITION PROTOCOLS

First-Pass Radionuclide Angiography-LV Function

1. Technetium 99m diethylamine triamine pentaacetic acid (DTPA) is the radionuclide of choice for standard first-pass radionuclide angiography (FPRNA) because of its renal excretion, minimizing patient radiation exposure. Tc-99m pertechnetate may also be used. Other technetium-based compounds, such as the technetium perfusion agents: sestamibi and tetrofosmin, are suitable. The short-lived radionuclides gold 195m and iridium 191m have been used for FPRNA but are not currently approved by the U.S. Food and Drug Administration.
2. The standard dose given is 25 mCi for both rest and exercise studies. A dose as low as 10 mCi may be used as an option in rest studies for multicrystal cameras. Since the study is count dependent and the single crystal cameras have limited count rate capabilities, doses of 20 to 25 mCi are typically recommended. When predicated by dosimetry considerations, lower doses may have to be used. Doses as low as 10 mCi may be used with reasonable clinical success but run the risk of inadequate count rates, especially for wall motion analysis. A rule that should be applied to test if enough counts have been acquired for a diagnostic clinical study is that the end-diastolic frame of the representative cycle should have more than 2500 counts in the LV region of interest (ROI).
3. Because of bolus prolongation and fractionation, no peripheral sites other than the antecubital (preferably medial) and external jugular veins are suitable for FPRNA. The study should not be attempted if those sites are not available.
4. Some users prefer larger-bore cannulae in the 14- to 16-gage range, but they are optional and not highly recommended because of the increased trauma. The cannula should be directly connected to a suitable length of intravenous tubing, preferably 12 to 20 inches. The free end of the tubing should be attached to a three-way stopcock with a sufficiently large bore to accommodate rapid injections. All intravenous connections should be lock-type rather than slip, to avoid contamination. A 10- to 20-mL saline bolus is used to flush the radionuclide bolus into the venous system. The saline bolus should be injected at a continuous, uninterrupted rate so that the entire 10 to 20 mL is injected in 2 to 3 seconds.
5. The injection for LV studies must be rapid. The full width at half maximum (FWHM) of the bolus transit in the superior vena cava should be less than 1 second and, if possible, less than 0.5 second. That will virtually guarantee a technically adequate study, all other variables being equal.
6. The most common position used is the upright, straight anterior view. Its advantages are the ease with which the chest may be stabilized against the detector and the straightforward approach to positioning the patient so that the left ventricle will be in the field of view (FOV). A transmission source or an initial injection of a 1-mCi tracer dose is recommended to ensure proper positioning. The

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Table 1. Acquisition parameters

	Rest	Exercise		For information, see paragraph
A. Radiopharmaceutical dose	Tc-99m	Tc-99m	Standard	1, 2, 13, 19
1. Multicrystal (LV and RV)	10–25 mCi	25 mCi	Standard	
2. Single crystal (LV and RV)	20–25 mCi/0.3–0.5 mL	20–25 mCi/0.3–0.5 mL	Standard	
3. Shunt	10–15 mCi/0.3–0.5 mL		Standard	
B. Injection site				3, 14
1. RV function	Antecubital vein	Antecubital vein	Standard	
	External jugular	External jugular	Optional	
2. LV function	Antecubital vein	Antecubital vein	Standard	
	External jugular	External jugular	Optional	
3. Shunt	Antecubital vein		Preferred	
	External jugular		Optional	
C. Intravenous cannula	18-gauge arm	18-gauge arm	Standard	4
	14-, 16-, or 20-gauge neck	14-, 16-, or 20-gauge neck	Optional	
D. Injection rate				5, 15, 16, 20
1. RV function	Slow (FWHM 2–3 s)	Slow (FWHM 2–3 s)	Preferred	
2. LV function	Rapid (FWHM <1 s)	Rapid (FWHM <1 s)	Standard	
3. Shunt	Rapid (FWHM <1 s)		Standard	
E. Position				6, 17, 21
1. RV function	Upright	Upright	Standard	
	Supine	Supine	Optional	
	20°–30° RAO	20°–30° RAO	Preferred	
	Anterior	Anterior	Optional	
2. LV function	Upright	Upright	Preferred	
	Supine	Supine	Optional	
	Anterior	Anterior	Standard	
	RAO	RAO	Optional	
3. Shunt	Anterior		Standard	
F. ECG signal				7, 22
1. RV and LV function	Multicrystal no	Multicrystal no	Standard	
	Single crystal yes	Single crystal yes	Standard	
2. Shunt	No		Standard	
G. Energy window frame time	120–160 keV	120–160 keV	Standard	8, 9, 23
1. LV and RV function	25 ms	25 ms	Standard	
	50 ms	50 ms	Optional	

Table 1. continued

	Rest	Exercise		For information, see paragraph
2. Shunt	50 ms		Standard	
	100 ms		Optional	
H. Total frames				10, 24
1. LV and RV function	2000	1500–2000	Standard	
2. Shunt	2000		Standard	
I. Matrix: Multicrystal				11, 25
1. RV and LV function	20 × 20	20 × 20	Standard	
	14 × 20	14 × 20	Optional	
2. Shunt	20 × 20 or 14 × 20		Standard	
J. Matrix: Single crystal				11, 25
1. RV function	64 × 64	64 × 64	Preferred	
	32 × 32	32 × 32	Optional	
2. LV function	32 × 32	32 × 32	Preferred	
	64 × 64	64 × 64	Optional	
3. Shunt	32 × 32 or 64 × 64		Standard	
K. Collimator: Single crystal				12, 18, 26
1. LV and RV function and shunt	High sensitivity	High sensitivity	Standard	
2. LV function	Ultrahigh sensitivity	Ultrahigh sensitivity	Preferred	
3. RV function	Ultrahigh sensitivity	Ultrahigh sensitivity	Optional	
4. Shunt	Diverging		Optional	
L. Collimator: Multicrystal				12, 18, 26
1. (SIM 400) (RV, LV, and shunt)	18 mm	18 mm	Standard	
	13 mm to 10 mCi	13 mm to 10 mCi	Optional	
	27 mm to 25 mCi	27 mm to 25 mCi	Optional	
System 77	1 inch	1 inch	Standard	

chief disadvantage of the anterior view is the anatomic overlap that may occur with the descending aorta and the basal portion of the inferoseptal wall and with the left atrium and the basal portion of the left ventricle. The shallow right anterior oblique (RAO) view helps eliminate both of those sources of overlap but is more difficult to standardize. A foam cushion cut at a 30° angle may be used for such positioning. The choice of upright versus supine positioning depends, to some degree, on the clinical situation. The upright position is, in general, preferred. Pulmonary background is reduced in the upright position, which enhances study quality. Positioning of the patient during treadmill exercise is a critical issue since the FOV of the detectors is small. It is suggested that a person should be behind the patient during peak stress for proper positioning of the chest in relation to the detector. This is of crucial importance so that the heart will be within the FOV during acquisition. A point source should also be placed in such a manner (left border of the sternum) that counts from the point source will be acquired during injection of the Tc-99m tracer. It is important to emphasize that for accurate studies of first pass during treadmill exercise, the heart, lung, and point source should all be in the FOV throughout the entire acquisition.

7. In high count rate studies, as are typically acquired with the multicrystal camera, there are enough counts at end diastole and end systole to reliably identify the end-diastolic and end-systolic frames without the aid of an electrocardiographic (ECG) signal. However, for single-crystal gamma cameras, count rates during the LV phase may occasionally be inadequate for reliable identification of the end-diastolic frames. Acquisition of an ECG signal is therefore highly recommended to facilitate data processing. In particular, data acquisition in gated list mode enables bad beat rejection after data has been collected, and enables reformatting images as 32×32 matrices in the event that unusually low counts are obtained. Single-crystal cameras vary widely in their count rate capabilities and thus in how appropriate they are for imaging a first-pass cardiac study. Several state-of-the-art gamma cameras can count at least 150,000 counts per second at a 20% loss of total counts. Use of cameras with lower count rate capabilities could lead to clinically significant inaccuracies in the determination of LVEF and particularly in the assessment of wall motion.
8. The 140-keV photopeak of Tc-99m ± 15% (140 ± 21 keV) is fairly standard and results in adequate count rates. This corresponds very closely to the 120- to 160-keV window used. The window may be widened to ±30% for low-dose injections.
9. Theoretically, the frame time should be varied to suit the heart rate at the time of acquisition. The relationship is fairly linear, with 50 milliseconds being quite adequate at heart rates of less than 80 beats/min and 25 milliseconds for heart rates of 125 to 175 beats/min. At very high heart rates, 10- to 20-millisecond frame times should be considered, especially if diastolic function is of interest. In practice, to avoid the potential errors that might occur if the frame time was constantly being manipulated, a standard of 25 milliseconds per frame is recommended for all acquisitions.
10. Fifteen hundred to 2000 frames should be sufficient, provided that these frames encompass the bolus injection and capture the entire LV phase of bolus transit.
11. The matrix size of the multicrystal camera is fixed due to the inherent design of the systems. However, for single-crystal cameras, the matrix size will largely depend on the computer system being used since most vendors do not offer many, if any, choices for dynamic studies. Most systems that have first-pass software support 64×64 acquisitions. Some systems also support 32×32 matrices. The latter is preferable because count density per pixel is maximized. The 64×64 matrix works reasonably well when count rates are high, but when counts are suboptimal or when the LVEF is high, there is a tendency for the end-systolic frame to have insufficient counts per pixel for assessment of regional wall motion. The actual minimum number of counts per frame needed varies depending on the number of frames per cardiac cycle, the actual LVEF, the amount of background radiation, and whether the study is performed to measure LVEF alone or in conjunction with an assessment of wall motion.
12. The choice of collimators depends on the objectives of the study and the dose to be injected. For standard rest and exercise studies using 20- to 25-mCi doses, the 18-mm-thick collimator provides a good compromise between sensitivity and spatial resolution for multicrystal cameras. A thinner collimator sacrifices spatial resolution but may be necessary for lower dose injections. For single-crystal cameras, most vendors offer high-sensitivity collimators and some offer ultrahigh-sensitivity collimators. It is helpful to categorize the collimators quantitatively in counts per mCi per minute because one vendor's high-sensitivity collimator may be equivalent to another vendor's ultrahigh-sensitivity collimator. For the purposes of first-pass

studies, a high-sensitivity collimator should provide approximately 12,000 to 24,000 counts $\cdot s^{-1} \cdot mCi^{-1}$. This number may vary significantly depending on crystal thickness and dead time of the system. For large (L)FOV systems, it may be desirable to shield part of the peripheral FOV to reduce unwanted pulse pileup, which increases the dead time of the system.

FPRNA-RV Function

13. Since the injection bolus reaches the right ventricle without significant dispersion, lower doses may be adequate; 10- to 25-mCi doses are acceptable. Of note, tricuspid regurgitation will fragment and disperse the radiotracer bolus and prolong RV transit time, often rendering FPRNA evaluation of both the left and right ventricles inadequate and invalid.
14. The use of the antecubital vein is appropriate for RV studies. The external jugular vein may be used but, unlike the LV study, it may result in too rapid an appearance and disappearance of the radionuclide from the chamber.
15. A 10- to 20-mL saline bolus is generally used to flush the radionuclide bolus into the venous system. The saline bolus should be injected at a continuous, uninterrupted rate so that the entire 10 to 20 mL is injected in 3 to 4 seconds.
16. To optimize assessment of RV function, the FWHM of the bolus in the superior vena cava should be 2 to 3 seconds, much slower than that for an LV study. The slower bolus increases the number of beats available for analysis. For assessment of biventricular function, a bolus with an FWHM of 1 to 2 seconds in the superior vena cava may be used as a compromise, realizing that assessment of neither ventricle is optimized.
17. A shallow (20° to 30°) RAO view is recommended to enhance right atrial–RV separation, which is the chief advantage of FPRNA over gated equilibrium radionuclide angiography for the measurement of RVEF.
18. As for LV function studies, the choice of collimators depends on the objectives of the study and the dose to be injected. For standard rest and exercise studies using 10- to 25-mCi doses, the 18-mm collimator from multicrystal cameras provides a good compromise between sensitivity and spatial resolution. A thinner collimator sacrifices spatial resolution but may be necessary for lower dose injections. For single-crystal cameras, the high-sensitivity collimator is the standard.

FPRNA-Shunt Study

19. A 10- to 15-mCi dose of the Tc-99m radiopharmaceutical is typically used.
20. The injection should be rapid for shunt studies. The premise of the shunt study is that the appearance in and clearance of the radionuclide bolus from the pulmonary circulation are monoexponential in character. Absent a shunt, the bolus should be a quite narrow, simple curve. A delayed bolus may result in a pulmonary curve that deviates enough from a monoexponential curve as to make the data uninterpretable. A 10- to 20-mL saline bolus is generally used to flush the radionuclide bolus into the venous system. The saline bolus should be injected at a continuous, uninterrupted rate so that the entire 10 to 20 mL is injected in 2 to 3 seconds.
21. Acquisition in the anterior view is best for imaging the lung fields, which are the areas of interest for the shunt study. If both lung fields cannot be visualized due to the detector size, the lung field of interest should be the right lung for suspected intracardiac shunts and the left lung for a suspected patent ductus arteriosus (PDA).
22. Since only pulmonary data will be quantified, an ECG signal is unnecessary.
23. Frame time is not crucial in a shunt study since the data will ultimately be analyzed using curves whose data points do not require more than 100 milliseconds' temporal resolution. Shorter frame times may be used since they may be added together during the analysis.
24. Total frames acquired should be 2000.
25. For multicrystal systems, the matrix is not an option. For single-crystal systems, a 64×64 matrix is appropriate. A 32×32 matrix may also be used to encompass both lungs in the FOV.
26. Spatial resolution is much less important in the shunt study than in studies performed to evaluate EF and wall motion. Standard high-sensitivity collimators are adequate. If available, a diverging collimator may be used.

PROCESSING PROTOCOLS

Measurement of Ventricular Function

Processing first-pass data has become increasingly automated and considerably faster than in previous years. However, it is unlikely that processing of first-pass data can ever be reliably, totally automated. There are too many variations possible in tracer transit due to

technical and/or pathophysiologic reasons for automated processing to be successful in all cases. The operator must be observant and careful at a few crucial steps in the processing to ensure consistently accurate results.

Preprocessing

Preprocessing of first-pass data is frequently performed, although it is not mandatory. Time smoothing, uniformity correction, and dead-time correction are options that are typically applied when supported by the software.

Processing

First-pass data processing can be divided into four major routines: creation of the initial time–activity curve (TAC), beat selection, and creation of the initial representative cycle, background correction, and creation of the final representative cycle. A fifth optional routine is that of motion correction.

The Initial TAC

Grouping or reformatting. The raw or preprocessed data should be grouped into 0.5- to 1.0-second images to facilitate drawing an ROI around the ventricle. If an ECG signal has been acquired, the raw or preprocessed data may be cyclically added using the R wave to identify end-diastolic frames, thus creating a preliminary representative cycle. The end-diastolic frame of that preliminary representative cycle may then be used to draw an initial ventricular ROI.

Ventricular ROI. The operator or the computer should draw an initial ventricular ROI. This ROI need not be highly accurate since it is only used for generating the initial TAC. A TAC of the raw or preprocessed data using the initial ROI should be displayed using the acquisition frame time.

Beat selection. Most first-pass software allows the operator to identify the first and last beats to be included in the representative cycle. End-diastolic and end-systolic frames may be identified automatically by the computer, but the operator must have the opportunity to override the computer to select only appropriate beats. Because of variable mixing in the chamber, it is advisable to select beats both before and after the beat with the maximum counts. Beats whose end-diastolic counts are below 50% of the maximum end-diastolic count should be excluded as long as this editing does not preclude a statistically adequate representative cycle. Premature ventricular beats and post-premature ventricular contraction (PVC) beats should be excluded. If there are few sinus beats, it may be difficult to generate a statistically adequate representative cycle.

Beat editing is an optional routine in which individual beats of varying duration may be time-corrected so that the final beat lengths are all identical. These algorithms are aided by the display of the actual R-wave trigger information shown superimposed on the transit curves. That approach typically involves an interpolation of the data, but actual end-systolic counts should always be preserved so that the EF is not altered by the time correction.

Background correction. Several approaches to background correction have been proposed. They include the lung frame method, the count threshold method, and the periventricular method. The lung method has been shown to give better results than the other two and is thus the preferred method. The periventricular background region is used as a standard in many single-crystal camera systems.

Lung frame method. In this approach, a frame of data just before the appearance of activity in the LV ROI is chosen as representative of the distribution of the background (nonventricular activity). This is a crucial step since variation in the background frame can substantially alter the calculated EF, volumes, and apparent wall motion. The selected frame should be visualized. That background ''mask,'' after appropriate normalization, is subtracted from the LV representative cycle. A washout factor must be applied to the background since the counts in the background are decreasing throughout the LV phase. This approach has been shown to produce results that compare favorably with contrast angiographic data and is somewhat better than either of the other two approaches.

Count threshold method. A frame of data just before the appearance of the radionuclide in the left ventricle is identified, and the counts in that frame become the new zero level for each subsequent frame of the LV phase.

Periventricular method. This method is quite analogous to the periventricular background method in gated equilibrium imaging. A horseshoe-shaped background ROI is drawn around the ventricle, usually 2 to 3 pixels wide and 1 to 2 pixels away from the LV border.

The final ROI. Once the background correction has been applied to the initial representative cycle, the end-diastolic and end-systolic frames should be displayed again and any necessary modifications of the initial ROI then performed.

Dual-ROI method. For first-pass studies acquired in the anterior view, a separate ROI for the end-diastolic and end-systolic frames is recommended. The operator must manually draw the final ROI on both frames. In drawing the end-systolic ROI, left atrial activity must be

excluded from the end-systolic counts. The LVEF calculated with the dual-ROI approach tends to be higher than that calculated with a single ROI because the valve plane is placed lower during systole compared to diastole.

Single-ROI method. With the single-ROI method, only an end-diastolic ROI is used. This approach works fairly well with studies acquired in the RAO projection, where there is better left atrial–LV separation. In the anterior view, the single-ROI method may result in spuriously low EFs because it can potentially include extra ventricular counts in the end-systolic ROI.

Motion correction. Motion correction of first-pass data is occasionally necessary for studies acquired during bicycle exercise and almost always necessary for studies acquired during treadmill exercise. Motion correction may be performed using either or both of two methods, the ''single-isotope'' method (internal correction method) or ''dual-isotope'' method (external marker correction). The dual-isotope method is preferred for treadmill exercise, while the single-isotope method is usually adequate for bicycle exercise.

Single-isotope motion correction. The position of the ventricle is determined in each frame of the representative cycle by applying a center-of-mass algorithm within an operator-defined ROI. The latter should greatly exceed the actual size of the ventricle. By calculating the average x, y location of the center of mass, the location of the ventricle $x_n y_n$ in any frame may be reregistered to x, y.

Dual-isotope motion correction. An external point source (americium 241, iodine 125) is applied to the chest, usually midsternally or just to the right of the sternum. A dual-energy acquisition is performed at peak exercise such that two first-pass studies are acquired, one using the external marker's photopeak and the other using the standard Tc-99m photopeak. After acquisition, the position of the marker is determined in each frame using a center-of-mass algorithm. The average x, y location of the marker is taken to represent the correct position of the marker had there been no motion. All data frames are then reregistered by the direction and magnitude of the displacement of the marker in that frame.

The final representative cycle. The finalized ROIs are then used to regenerate the TAC and the final representative cycle is created from that curve using the previously determined beat selection. It is this representative cycle that will be used to generate all the quantitative results describing ventricular function.

FPRNA: Quantitation of Results

LVEF. The LVEF is calculated from the final background-corrected representative cycle as follows: (End-diastolic counts End-systolic counts)/End-diastolic counts. On occasion, it is impossible to correct accurately for background activity (very delayed bolus, markedly prolonged RV tracer transit, and so on). In that case, it is appropriate to report an estimated LVEF or LVEF range based on the uncorrected data.

Systolic emptying rates. Systolic emptying rates such as the peak ejection rate may be calculated by applying a Fourier filter (third- to fifth-order harmonic) to the LV representative cycle curve and then taking the first derivative of that filtered curve. The peak ejection rate should be expressed in end-diastolic volumes per second.

Diastolic filling rates. Diastolic filling rates such as the peak filling rate may be calculated by applying a Fourier filter (third- to fifth-order harmonic) to the LV representative cycle curve and then taking the first derivative of that filtered curve. The peak filling rate should be expressed in end-diastolic volumes per second. The time-to-peak filling rate may be calculated and expressed in milliseconds.

Ventricular volumes. LV end-diastolic volume may be measured using either a geometric or count-proportional technique. In the geometric approach, the end-diastolic frame of the representative cycle is displayed using a threshold for edge detection. The area of the left ventricle is measured using the pixel area and the known size of a pixel. The longest length of the left ventricle is identified by the operator and end-diastolic volume calculated using the modified Sandler and Dodge equation. In the countproportional approach, the required data are the total counts in the left ventricle, the counts in the hottest pixel in the left ventricle, and the area of a pixel (m) in centimeters. The end-diastolic volume is then calculated as $1.38\ m^{3/2}\ R^{3/2}$, where R is total LV counts/counts in the hottest pixel.

Left-to-Right Shunt Study

The input function for the first-pass shunt study is a high-count density TAC obtained from a pulmonary ROI. In practice, either the left lung, the right lung, or both may be used. In most cases, the right lung is preferred because it is easier to create a pulmonary ROI that is free of contamination from the cyclic changes in counts in the left heart and great vessels. Regardless of the acquisition frame time, the pulmonary curve should be displayed at a frame time of approximately 100 to 300 milliseconds. That allows the operator to easily visualize the entire curve for qualitative assessment of the presence or absence of a shunt. Not infrequently, the raw curve requires time smoothing to eliminate high-frequency contamination of the curve from cardiac chamber or great vessel counts or from random noise.

The first frame of the curve should unequivocally represent pulmonary activity rather than any superior vena cava, right atrial, or RV activity because the shape of the early part of the curve will determine the shape of the subsequent mathematical fit. It may be helpful to mask out the superior vena cava and right heart from the image before drawing the pulmonary ROI. Careful attention to the statistical content of the pulmonary curve and its freedom from contamination is crucial. The operator may then apply either a gamma variate or an exponential fit to the raw data. Qualitative assessment of the closeness of the fitted curve to the raw curve is important. Varying the initial frame of the fit and the final frame of the fit may be necessary to produce the best fitted curve possible. The fitted curve may then be subtracted from the raw data to leave the shunt component behind, which can, itself, be fitted with another curve that represents the shunt component. The shunt ratio *Qp*:*Qs* is then calculated as $(A1 + A2)/A1$, where $A1$ is the area under the primary fitted curve and $A2$ is the area under the secondary (shunt) fitted curve.

INTERPRETATION AND REPORTING

General Comments

The interpretation of first-pass data should be performed in a consistent, methodical manner, with particular attention to the quality of the data. Unlike equilibrium radionuclide angiography, in which a quick inspection of the cinematic display of the cardiac cycle is sufficient to reassure the interpreting physician of the adequacy of the data, the first-pass study requires considerably more attention to the details of data acquisition and processing to provide consistently accurate interpretations. The final representative cardiac cycle that is used to generate both the quantitative results and the qualitative wall motion assessment can be affected by many factors, including the adequacy of the injection bolus, the count rate, the number and type of beats chosen for inclusion, the manner in which background activity is determined, and occasionally, patient motion. Even in laboratories with extensive experience and well-defined and well-executed acquisition and processing techniques, unavoidable patient-to-patient variability and different cardiac and pulmonary physiology, as well as some degree of interobserver variability in processing, lead to variability in the end product. The physician must therefore exercise due diligence during interpretation of the results (Table 2).

Certain data must be routinely available so that the interpreting physician may quickly assess the technical adequacy of the data and the accuracy of the processing. Most commercial software routines automatically save enough of the intermediate steps of processing to enable the physician to review quickly the processing either directly on the computer display or by reference to hard copy.

Display

27. The final representative cycle should be displayed in a cinematic, endless loop format. Most authorities use a color display in contrast to the recommended display for equilibrium images. The lower pixel count density and the subtle change from cardiac cavities to background make a color display useful. The cine display is typically time-smoothed during data processing and should not need additional smoothing for display. Spatial smoothing may be used after processing if the data are particularly count-poor, but it should not be necessary for the average study. It is preferable to normalize the image to the peak activity in the ventricle because aortic or left atrial activity may be higher, thus making it more difficult to appreciate the count changes in the ventricles. Cinematic displays of the bolus transit through the heart and great vessels are helpful in analyzing aberrations of tracer transit that may occur in patients with congenital anomalies.
28. Hard-copy displays are essential to study interpretation. TACs representing the bolus and the RV and LV phases of the bolus transit, as well as a final representative cycle time–activity (volume) curve, must be available for proper interpretation. Color hard-copy displays of parametric images may be valuable aides in study interpretation. Such displays should not be used to the exclusion of the cinematic display of the representative cycle.

Quality Control

29. *The bolus*. The adequacy of a bolus may be defined quantitatively by generating a TAC from an ROI that includes the superior vena cava. The FWHM of such a curve should ideally be less than 1 second. As a routine quality check, it is helpful to inspect the TAC of the bolus. Alternatively, one may inspect a sequence of images from the early portion of the study to qualitatively assess the bolus. Serial 1-second images are useful for that purpose. The bolus may be assessed as good (FWHM <1 second), adequate (1 to 1.5 seconds), delayed (>1.5 seconds), or split (more than one discrete peak in the TAC). The split bolus is particularly problematic and may preclude accurate data processing. Identification of a delayed or split bolus alerts the physician to the possibility of oversubtraction of

Table 2. First-pass radionuclide angiography: guideline for interpretation

		For information, see paragraph
A. Display		
1. Cinematic display of representative cycle	Standard	27
a. Time smoothing	Standard	27
b. Spatial smoothing	Optional	27
c. Normalization	Standard	27
2. Hard copy 2		
a. Intermediate processing steps	Standard	28
b. Functional images	Optional	28
c. TACs	Standard	28
B. Quality control		
1. Bolus	Standard	29
2. Count statistics	Standard	30
3. Tracer transit	Standard	31
4. Beat selection	Standard	32
5. Background selection	Standard	33
6. Patient motion	Standard	34
C. Results		
1. Cardiac rhythm and conduction	Standard	35
2. Chamber sizes		
a. Qualitative	Standard	36
b. Quantitative	Preferred	36
3. Regional wall motion		
a. Qualitative	Standard	37
b. Quantitative	Optional	37
4. LVEF	Standard	38
5. RVEF	Optional	38
6. LV diastolic filling		
a. Qualitative	Standard	39
b. Quantitative	Optional	39
D. Exercise/intervention studies		
1. Display	Standard	40
2. Regional wall motion: comparison to rest	Standard	41
3. Chamber sizes: comparison to rest	Standard	42
4. EFs: comparison to rest	Standard	43
E. Conclusion		
1. Comparison to previous studies	Standard	44
2. Correlation with clinical findings	Standard	45

background and the resultant spurious increase in LVEF, decrease in LV volume, and overestimation of regional wall motion.

30. *Count statistics*. The adequacy of the count rate may be assessed by use of either the unprocessed data or the representative cycle. When examining the unprocessed data, the count rate in the whole FOV during the RV phase of the study should optimally be greater than 200,000 cps with a multicrystal system and greater than or equal to 150,000 cps on a single-crystal system. When count rates drop below 100,000 cps, it is highly unlikely that adequate studies will be obtained. Alternatively, and more accurately, the count rate of the representative cycle can be checked. This approach is more accurate because it is the representative cycle that is used to generate all quantitative results, and counts in the representative cycle may be inadequate even when the count rate on the raw data is adequate if there are insufficient beats for analysis or background

over-subtraction. In general, LV end-diastolic counts in the representative cycle should not be less than 2000 cps and should preferably exceed 4000 cps. High-resolution wall motion images will require greater than 5000 cps.

31. *Tracer transit*. The transit of the radionuclide should be inspected in every case. Alterations or anomalies of tracer transit may be detected visually by examining serial static images or by a cinematic display of the bolus transiting the central circulation. For example, asymmetric pulmonary transit time or asymmetric maximal tracer concentration may indicate pulmonary vascular pathology or unilaterally decreased pulmonary volume. A cine display may be particularly helpful when the transit seems anomalous. The most common disturbance of tracer transit is prolongation of the transit time through either or both ventricles. Recognition of a prolonged transit time is important because of the potential diagnostic implications and because of the impact on background correction, which in turn affects EF, volumes, and wall motion. Physiologic causes of prolonged tracer transit include valvular insufficiency, severely depressed ventricular function, atrial fibrillation, and a left-to-right shunt. Combining image information such as an enlarged left atrial appendage (see below) and a prolonged tracer transit through the left ventricle suggests mitral valve disease, whereas prolonged LV tracer transit and an enlarged ascending aorta suggest aortic valve disease.
32. *Beat selection*. A hard copy of the TAC should be generated during processing so that one may confirm that the appropriate beats have been selected for inclusion in the representative cycle. Unless the number of beats is very limited, one should preferably select beats whose end-diastolic counts are 70% of the peak end-diastolic counts or greater.
33. *Background selection*. The same curve used to confirm appropriate beat selection may be used to confirm that an appropriate frame was chosen for background correction. A frame as close to the beginning of the LV phase but not including LV activity is desired. Viewing the background frame image is helpful in determining that LV activity is not included and in visualizing any residual activity in the right ventricle that could result in over-subtraction of background. On occasion, the lung frame method of background correction may not be accurate because of poor RV–LV temporal separation. In that case, the physician should demand that a representative cycle be created that has not been subjected to background correction. The uncorrected representative cycle is always generated during the processing but may not be stored. Viewing this image in cine loop format after manually subtracting the background will allow an adequate assessment of regional wall motion.
34. *Patient motion*. Motion of the patient is rarely, if ever, a problem on a resting study. However, motion of the chest during acquisition of an exercise study is seen frequently during treadmill exercise and occasionally during bicycle exercise. Motion should be suspected when typical distortions of the LV TAC are noted and should be confirmed by viewing a cine display of the bolus traveling through the chambers. During treadmill exercise, chest wall motion may be corrected with the use of an external point source. The integrity of the point source, and especially its appearance in each frame of the study, should be confirmed.

Results (Table 3)

35. *Cardiac rhythm and conduction*. Interpretation of the data may be influenced by the rhythm during the acquisition. For example, frequent PVCs, ventricular bigeminy, or very irregular atrial fibrillation may affect the EF or regional wall motion. In the setting of ventricular bigeminy, for example, no true sinus beat EF can be determined. The diagnostic and prognostic significance of post-PVC beats is not completely understood. With atrial fibrillation, the representative cycle may consist of beats with widely varying R–R intervals and, hence, with different volumes and EFs. Pacemaker rhythm confers its own unique contraction sequence, which starts at the apex and proceeds to the base. The latter can be recognized from the cinematic display of the representative cycle. A phase image may be helpful in recognition of this pattern.

    Both regional wall motion and LVEF are typically altered by left bundle branch block. Because most first-pass studies are acquired in the RAO or anterior projections, paradoxical septal motion cannot be detected; however, one may see what appear to be inferoapical or anteroapical wall motion abnormalities. A phase image may aid in recognizing this phenomenon, although it is usually apparent on the cinematic display of the representative cycle. Right bundle branch block does not affect the LV contraction pattern.
36. *Chamber sizes*. Because the overwhelming majority of first-pass studies are performed to evaluate the left ventricle, the final representative cycle will show the left ventricle, the left atrium (in particular its appendage), and the ascending aorta. Most of the

Table 3. First-pass radionuclide angiography: guideline for reporting

		For information, see paragraph
A. Demographics		
1. Name	Standard	
2. Gender	Standard	
3. Age	Standard	
4. Date(s) of acquisition(s)	Standard	
5. Medical record identifier (inpatient)	Standard	
6. Height/weight (taking into account BSA)	Standard	
B. Acquisition parameters		
1. Type(s) of acquisition(s) (rest/exercise/intervention)	Standard	
2. Radionuclide and doses	Standard	45
3. Injection site	Standard	45
4. Indication for study	Standard	48
5. Study quality	Standard	47
C. Results: Hemodynamic and exercise/intervention variables		
1. Rest HR and BP, cardiac rhythm	Standard	46
2. Exercise HR and BP, %MPHR, METS	Standard	46
3. Exercise symptoms, reason for stopping	Standard	46
4. Exercise ECG changes/arrhythmia	Standard	46
D. Results: Resting RNA data		
1. Chamber sizes		
a. Qualitative	Optional	36
b. Quantitative	Standard	36
2. Regional wall motion		
a. Qualitative	Standard	37
b. Quantitative	Optional	37
3. EFs	Standard	38
4. Abnormalities of tracer transit	Standard	31
E. Results: Exercise/intervention RNA data		
1. LV size: Change from rest		
a. Qualitative	Standard	42
b. Quantitative	Preferred	42
2. LV regional wall motion: Change from rest	Standard	41
3. LVEF: Change from rest	Standard	43
4. RVEF: Change from rest	Optional	43
5. Abnormalities of tracer transit	Standard	44
F. Conclusion		
1. Normal/abnormal	Standard	48
(definite, probable, equivocal)	Optional	48
2. Assessment of severity of findings	Standard	48
(diagnostic/prognostic)		48
3. Relationship to perfusion data if acquired	Optional	48
4. Comparison to previous studies	Standard	49

BSA, Body surface area; *HR*, heart rate; *BP*, blood pressure; *%MPHR*, maximum predicted heart rate; *METs*, metabolic equivalents; *RNA*, radionuclide angiography.

left atrium is overlapped with the ascending aorta, and its size is difficult to assess. However, when the left atrium is very dilated, its appendage is quite prominent in the anterior view, and the aortic root will appear to be dilated. Judging the size of the left ventricle qualitatively is more difficult on a first-pass study than on an equilibrium study because one does not have all the surrounding

chambers and great vessels in the same image as references. With enough experience, moderate to severe degrees of LV chamber enlargement can be appreciated. Right atrial, RV, and pulmonary arterial sizes can be evaluated on cinematic display or on serial static 0.5- to 1.0-second images from the raw data but are not particularly reliable.

Actual measurement of LV volume may be performed with either geometric or count-based approaches and offers a more consistent and accurate assessment of chamber size. Normal values for the left ventricle should be established for each laboratory because they will vary depending on the type of processing used, especially the type of background correction and the patient's position during the acquisition (i.e., supine, semisupine, or upright).

37. *Regional wall motion*. The cinematic display of the representative cycle should be viewed and regional wall motion assessed qualitatively by use of the conventional terms of hypokinesis, akinesis, and dyskinesis. For hypokinesis, the qualifiers of mild, moderate, and severe are useful for communicating the severity of the abnormality. In addition, the extent and location of the abnormality should also be reported, such as the basal (proximal) half or the apical (distal) quarter of the anterior wall. An aneurysm should be identified when an akinetic or dyskinetic segment can be clearly and discretely distinguished from the adjacent contractile myocardium. When available, previous studies should be compared by use of side-by-side cine analysis. Standardized nomenclature for the myocardial segments visualized in the typical FPRNA study (i.e., acquired in the anterior view) is shown in Figure 1. If biplane FPRNA is performed, segmental analysis may also be applied to the left anterior oblique projection. It is recommended that the visualized segments be designated as the basal anterolateral, mid anterolateral, apical, mid inferoseptal, and basal inferoseptal segments. For a left anterior oblique acquisition, the visualized segments include the septal, inferoseptal, inferoapical, inferolateral, and lateral segments.

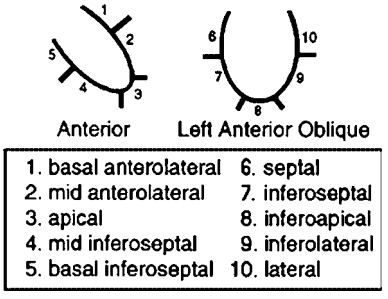

Figure 1. FPRNA segmentation.

Even though the final representative cycle is corrected for background, it may be necessary to display the cine with the lower level raised to 10% to 20% depending on the signal-to-noise ratio in the study. Any one of the number of color schemes may be used to view the cine. Whether one is more representative of actual wall motion than another is speculative. The operator should choose the scheme that works best clinically, but one should avoid color tables that condense all the three-dimensional information into a few colors that make the image appear two-dimensional, as if all the information were in the moving edges.

Many parametric images are available to the interpreting physician that may be used to reinforce one's subjective opinion. Occasionally, an abnormality will be evident on a parametric image that is not obvious on the cinematic display, especially when the regional dysfunction is occurring in a plane that is perpendicular to the detector. The parametric images may be thought of as an independent, unbiased observer similar to the way in which quantitative displays of perfusion images are used. They are also useful as quantitative measures of regional dysfunction. For example, one physician's impression of moderate hypokinesis may be different than another physician's, but a regional EF of 28% is clear to anyone receiving the information. The most commonly used images are the regional EF image, the stroke volume image, and the amplitude and phase images. The latter three may be used in processing, as well as in interpretation. One must keep in mind that the accuracy of the parametric image is highly dependent on the statistics in the image and may be influenced by translational movement of the heart; therefore, the parametric image should not be used to the exclusion of the representative cycle cine because the latter gives the operator the best visual feedback on the statistical quality of the data. Very little literature is available to document the accuracy of parametric images for diagnosis.

38. *LVEF and RVEF*. The LVEF is calculated from the background-corrected end-diastolic and end-systolic counts in either ventricle. Published ranges for a normal EF vary, but most laboratories accept a range of 50% to 80% for the left ventricle. The variability of the LVEF has been reported to be ±4% at rest for the same individual studied on different days. It is very important when interpreting the LVEF, and most especially when interpreting changes in LVEF

from one study to another, to keep in mind that the LVEF is not a fixed number for any patient. It will vary with the heart rate, the blood pressure, the level of circulating catecholamines, position (upright vs supine), and medications. When there are an adequate number of beats to choose for the EF calculation, it is preferable to select those beats whose end-diastolic counts are 70% of the peak end-diastolic counts or greater. The normal values for the RVEF vary with the type of processing used. With the use of separate end-diastolic and end-systolic ROIs, the lower limit of normal can be expected to be 40%, ranging up to 65%.

39. Diastolic filling of the left ventricle may be assessed by qualitative inspection of the TAC (volume curve) of the LV representative cycle. Obviously, decreased early rapid filling, a prolonged time to peak filling, and an increase in the atrial contribution to filling may be recognized by visual inspection of the LV volume curve. The quantitative values for peak early filling and the time to peak filling should be expressed in end-diastolic volumes per second and in milliseconds, respectively. The atrial contribution to filling may be expressed as a ratio of the atrial to early peak filling or vice versa. The atrium typically contributes 15% to 25% of total LV filling. The interpreting physician should not accept any diastolic values without confirmation by visual inspection of the LV volume curve.

    It is difficult to evaluate diastolic filling during exercise because the increase in heart rate usually results in a loss of the transition between early peak filling and atrial filling. At best, one can measure peak diastolic filling, but without the requisite temporal sampling necessary for high heart rates (i.e., 10 to 20 ms/frame), any measured values may not be reliable. Some investigators have used filling fractions (i.e., the fraction of filling achieved during the first third or first half of diastole). It is not clear that such values offer any advantage over the conventional values, and they are certainly a departure from the values typically measured in gated equilibrium studies.

Exercise/Intervention Studies

40. The representative cycles of both resting and exercise or pharmacologic intervention studies should be viewed in a split-screen cinematic display. Each study should be normalized to itself.
41. Regional wall motion of an exercise or intervention study should be compared visually with regional wall motion of the resting study by use of standard qualitative or semiquantitative terms (see paragraph 11). During exercise or during administration of inotropic or afterload-reducing agents, regional wall motion is expected to increase. Regional wall motion may decrease during ischemia, during protocols that result in abrupt increase in afterload such as isometric or sudden strenuous aerobic exercise, or during administration of drugs that acutely increase afterload. A semiquantitative scoring system or quantitative regional EFs may be useful for comparison of rest to exercise or interventional studies.
42. The size of the left ventricle may be qualitatively evaluated on the cine displays. During exercise in the upright position, LV volume usually increases. The magnitude of the increase is typically in the 10% to 20% range, although larger increases do occur in control subjects. When the volume increases by 50% or greater above baseline, coronary artery disease should be suspected even in the absence of a regional wall motion abnormality, especially if there is a concomitant, significant drop in LVEF. LV volume may fail to increase or may actually decrease even in the upright position in patients with pericardial or valvular heart disease.
43. During exercise in the upright position, one can anticipate that the EFs of both ventricles will increase. At one point in time, failure to increase the LVEF during exercise was invariably considered pathologic. However, it is quite clear that some individuals may show a flat response to exercise and, occasionally, even a decrease in EF (especially elderly subjects) in the absence of coronary or valvular heart disease. The higher the resting EF, the less of an increase one tends to see during exercise. For diagnostic purposes, an absolute value of exercise EF may be more useful than the change from rest to exercise. Most normal individuals will have a peak exercise LVEF of 56% or greater. A decrease in LVEF to less than 56% should be considered abnormal in individuals aged younger than 70 years, but in the absence of regional dysfunction, the finding is not specific for coronary artery disease. The change in EF during exercise may also be influenced by the type of exercise protocol used. A standard graded exercise protocol should always be used.

    RVEF typically increases during exercise but may decrease in patients with pulmonary hypertension, including those in whom pulmonary hypertension develops during exercise, such as those with mitral stenosis or severe exercise-induced LV dysfunction. In particular, patients with proximal right coronary artery lesions may show decreases in RVEF during exercise.

44. LV tracer transit may be prolonged during exercise because of the appearance of mitral insufficiency resulting from LV ischemia. This finding may be recognized most readily on a TAC of the bolus transit through the left ventricle. Occasionally, this finding is accompanied by exercise-induced enlargement of the left atrium.

Conclusion

45. The radionuclide and doses used for the study, as well as the injection site, should be permanently archived in the report. These are more important for future reference in case a patient returns to the laboratory for serial studies. Having the data is particularly useful in avoiding pitfalls if the previous study was technically suboptimal.
46. The report should include the most important variables from a stress or intervention that will help the referring physician assess the clinical significance of the findings. These variables are also important because they have independent diagnostic and prognostic information.
47. Overall study quality should be mentioned in the report. This serves to appropriately increase or decrease the confidence of the physicians using the report for clinical decision making. It is also useful for subsequent screening of studies for inclusion in research databases.
48. The initial interpretation of the study should be made without reference to clinical data to avoid bias. The physician should then correlate the findings and interpretation with the clinical information to avoid an obvious misinterpretation and to guarantee that the clinical question has been addressed. Including the indication for the study in the report serves to focus the interpreting physician's attention to the clinical question and is also useful for subsequent coding issues related to reimbursement. Studies should be classified as normal or abnormal. Categories of probably normal, equivocal, and probably abnormal may be added. Both the diagnostic and prognostic contents of the data should be addressed. If perfusion scan data are available, a statement about the significance of the two datasets is appropriate.
49. Whenever previous studies are available, the cine displays of the representative cycles should be displayed side by side. When rest and exercise/intervention data are available, a quad-screen display is optimal. Interpretation of serial changes in EFs should always take into account differences in the heart rates, blood pressures, and medications.

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Suggested Reading

1. Aroney CN, Ruddy TD, Dighero H, et al. Differentiation of restrictive cardiomyopathy from pericardial constriction: Assessment of diastolic function by radionuclide angiography. J Am Coll Cardiol 1989;13:1007-14.
2. Berger HJ, Matthay RA, Loke J, et al. Assessment of cardiac performance with quantitative radionuclide angiocardiography: RV ejection fraction with reference to findings in chronic obstructive pulmonary disease. Am J Cardiol 1978;41:897-905.
3. Berger H, Reduto L, Johnstone D, et al. Global and regional left ventricular response to bicycle exercise in coronary artery disease assessment by quantitative radionuclide angiocardiography. Am J Med 1979;66:13-21.
4. Borges-Neto S, Coleman RE, Jones RH. Perfusion and function at rest and treadmill exercise using technetium-99m sestamibi: Comparison of one and two day protocols in normal volunteers. J Nucl Med 1990;31:1128-32.
5. Borges-Neto S, Coleman RE, Potts JM, Jones RH. Combined exercise radionuclide angiocardiography and single photon emission computed tomography perfusion studies for assessment of coronary disease. Semin Nucl Med 1991;21:223-9.
6. Borges-Neto S, Shaw L. The added value of simultaneous myocardial perfusion and left ventricular function. Curr Opin Cardiol 1999;14:460-3.
7. Borges-Neto S. Perfusion and function assessment by nuclear cardiology techniques. Curr Opin Cardiol 1997;12:581-6.
8. Campos CT, Chu HW, D'Agostino HJ Jr, Jones RH. Comparison of rest and exercise radionuclide angiocardiography and exercise treadmill testing for diagnosis of anatomically extensive coronary artery disease. Circulation 1983;67:1204-10.
9. DePace NL, Iskandrian AS, Hakki A, et al. Value of left ventricular ejection fraction during exercise in predicting the extent of coronary artery disease. J Am Coll Cardiol 1983;1:1002-10.
10. Foster C, Dymond DS, Anholm JD, et al. Effect of exercise protocol on the left ventricular response to exercise. Am J Cardiol 1983;51:859-64.
11. Friedman JD, Berman DS, Kiat H, et al. Rest and treadmill exercise first-pass radionuclide Ventriculography: Validation of left ventricular ejection fraction measurements. J Nucl Cardiol 1994;4:382-8.
12. Gal R, Grenier RP, Carpenter J, et al. High count first-pass radionuclide angiography using a digital gamma camera. J Nucl Med 1986;27:198-206.
13. Gal R, Grenier RP, Schmidt DH, Port SC. Background correction in first-pass radionuclide angiography: Comparison of several approaches. J Nucl Med 1986;27:1480-6.
14. Gal R, Grenier RP, Port SC, Dymond DS. Left ventricular volume calculation using a count-based ratio method applied to first-pass radionuclide angiography. J Nucl Med 1992;33:2124-32.
15. Johnson LL, Rodney RA, Vaccarino RA, et al. Left ventricular perfusion and performance from a single radiopharmaceutical and one camera. J Nucl Med 1992;33:1411-6.
16. Jones RH, McEwen P, Newman GE, et al. Accuracy of diagnosis of coronary artery disease by radionuclide measurement of left ventricular function during rest and exercise. Circulation 1981;64:586-601.

17. Lee KL, Pryor DB, Pieper KS, Hasell FE Jr. Prognostic value of radionuclide angiography in medically treated patients with coronary artery disease. Circulation 1990;82:1705-17.
18. Maltz DL, Treves S. Quantitative radionuclide angiocardiography: determination of Qp:Qs in children. Circulation 1973;47:1048-56.
19. Morrison DA, Turgeon J, Quitt T. Right ventricular ejection fraction measurements: contrast ventriculography versus gated blood pool and gated first-pass method. Am J Cardiol 1984;54: 651-3.
20. Nichols K, DePuey EG, Gooneratne N, et al. First-pass ventricular ejection fraction using a single crystal nuclear camera. J Nucl Med 1994;35:1292-300.
21. Nichols K, DePuey EG, Rozanski A. First-pass radionuclide angiocardiography using single crystal gamma cameras. J Nucl Cardiol 1997;4:61-73.
22. Nickel O, Schad N, Andrews EJ, et al. Scintigraphic measurement of left ventricular volumes from the count-density distribution. J Nucl Med 1982;23:404-10.
23. Philippe L, Mena I, Darcourt J, French WJ. Evaluation of valvular regurgitation by factor analysis of first-pass angiography. J Nucl Med 1988;29:159-67.
24. Potts JM, Borges-Neto S, Smith LR, Jones RH. Comparison of bicycle and treadmill radionuclide angiocardiography. J Nucl Med 1991;32:1918-22.
25. Reduto LA, Wickemeyer WJ, Young JB, et al. Left ventricular diastolic performance at rest and during exercise in patients with coronary artery disease. Circulation 1981;63:1228-37.
26. Updated imaging guidelines for nuclear cardiology procedures, part 1. J Nucl Cardiol 2001;8:G1-58.
27. Upton MT, Rerych SK, Newman GE, et al. The reproducibility of radionuclide angiographic measurements of LV function in normal subjects at rest and during exercise. Circulation 1980;62:126-32.
28. Verani MS, Lacy JL, Guidry GW, et al. Quantification of left ventricular performance during transient coronary occlusion at various anatomic sites in humans: a study using tantalum-178 and a multiwire gamma camera. J Am Coll Cardiol 1992;19:297-306.
29. Williams KA, Bryant TA, Taillon LA. First-pass radionuclide angiographic analysis with two regions of interest to improve left ventricular ejection fraction accuracy. J Nucl Med 1998;39:1857-61.