Society of Nuclear Medicine Procedure Guideline for Gated Equilibrium Radionuclide Ventriculography

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I. Purpose

The purpose of this guideline is to assist nuclear medicine practioners in recommending, performing, interpreting, and reporting the results of gated equilibrium radionuclide ventriculography.

II. Background Information and Definitions

Gated equilibrium radionuclide ventriculography (RVG) is a procedure in which the patient's red blood cells (RBCs) are radiolabeled and electrocardiograph (ECG)-gated cardiac scintigraphy is obtained. Single or multiple measurements of left and/or right ventricular function are obtained. Alternative terminologies for this technique include gated cardiac blood-pool imaging, multigated acquisition (MUGA), and gated equilibrium radionuclide angiography (RNA).

Data are collected from several hundred cardiac cycles to generate an image set of the beating heart that is presented as a single, composite cardiac cycle. The method can be used to assess (a) regional and global wall motion; (b) cardiac chamber size and morphology; and (c) ventricular systolic and diastolic function, including left and right ventricular ejection fractions (LVEF and RVEF, respectively). An RVG may be acquired at rest, during exercise, or after either pharmacologic or mechanical interventions.

III. Common Indications

A. Parameters obtained from RVG include the following:
   1. Global ventricular systolic function
   2. Regional wall motion
   3. Ventricular volumes (qualitative or quantitative)
   4. Responses of above parameters to exercise or other interventions
   5. Systolic and diastolic function indices
   6. Stroke volume ratios

B. Common clinical settings in which RVG may be useful include:
   1. Known or suspected coronary artery disease (CAD)
      a. CAD without myocardial infarction (MI)
      b. Remote MI
      c. Acute MI (however, these patients usually should not undergo exercise stress in the first 48 hours after acute MI)
   2. To help distinguish systolic from diastolic causes of congestive heart failure (CHF) in patients with known or suspected CHF
   3. Evaluation of cardiac function in patients undergoing chemotherapy
   4. Assessment of ventricular function in patients with valvular heart disease

   An RVG may be used in the conditions listed above for (a) determining long-term prognosis; (b) assessing short-term risk (e.g., preoperative evaluation); and (c) monitoring response to surgery or other therapeutic interventions.

IV. Procedure

A. Patient Preparation
   1. Rest

      No special preparation is required for a resting RVG. A fasting state is generally preferred. It is not necessary to withhold any medications. The electrodes used for cardiac gating must be placed securely on the skin to ensure an optimal ECG signal.
   2. Exercise

      The patient should be fasting for at least 3–4 hours before the study and should be both hemodynamically and clinically stable. Exercise stress, in the form of supine or upright ergometry, is generally preferred. Patients who are unable to exercise for noncardiac

reasons may undergo pharmacologic stress with a positive inotropic agent. It is recommended that medications that may alter the heart rate response be withheld unless medically contraindicated or the efficacy of the medication is being tested by the exercise test.

Life support instrumentation and cardiac resuscitative drugs must be available in the immediate vicinity of the stress laboratory. A physician or other personnel trained in advanced cardiac life support (ACLS) must be immediately available during the stress and recovery phases. Continuous, preferably 12-lead ECG monitoring must also be performed throughout all phases of the stress study. Intermittent blood pressure measurement and ECG tracings should be performed before, during, and in the recovery phases of the stress study. The patient should be clinically observed during and immediately after the stress test. Any abnormalities in symptomatology, hemodynamics, or the ECG should be monitored until resolved.

B. Information Pertinent to Performing the Procedure

An adequate history and cardiovascular examination should be obtained before diagnostic evaluation. Specific areas to be reviewed include the indication(s) for testing, medications, symptomatology, cardiac risk factors, and prior cardiac procedures (diagnostic or therapeutic). The patient's cardiac rhythm should be noted, because marked heart rate variability may limit the ability to both perform and interpret the RVG. Physical limitations may limit or preclude the performance of a study requiring physical exercise. A resting 12-lead ECG should be reviewed before an exercise study.

C. Precautions

1. It is mandatory that Occupational Safety and Health Administration guidelines for safe handling of human blood products be followed at all times when techniques labeling autologous RBCs are used.
2. When an in vitro method is used for radiolabeling autologous RBCs, a fail-safe policy and procedure must be in place and implemented to assure that administration of labeled cells to the wrong patient is prevented.
3. Patients with potentially unstable cardiac rhythms (e.g., paroxysmal supraventricular or ventricular tachycardia) or implanted devices (e.g., implantable defibrillators) may require special precautions, because heart rate response to exercise may be unpredictable.

D. Radiopharmaceuticals

For the adult, the usual administered activity is 555–1110 MBq (15–30 mCi) autologous RBCs labeled with Tc-99m using the in vivo, modified in vivo, or in vitro techniques. The usual administered activity in children is 7–15 MBq/kg (0.2–0.4 mCi/kg), with a minimum dose of 70–150 MBq (2–4 mCi). The largest absorbed radiation dose to an organ is that to the heart (about 0.02 mSv/MBq). Tc-99m–labeled RBCs distribute within the blood-pool with an estimated volume of distribution of approximately 4%–7% of body weight. The estimated biological half-life is approximately 24–30 hours. Approximately 25% of the administered

Radiation Dosimetry for Adults

Radiopharmaceutical	Administered activity MBq (mCi)	Organ Receiving the largest radiation dose mGy per MBq (rad per mCi)	Effective dose mSv per MBq (rem per mCi)
Tc-99m labeled red blood cells[1]	555 – 1110 i.v. (15 – 30)	0.023 Heart (0.085)	0.0085 (0.031)
Tc-99m albumin[2]	370 – 740 i.v. (10 – 20)	0.020 Heart (0.074)	0.0079 (0.029)

[1]ICRP 53, p. 210
[2]ICRP 53, p. 173

Radiation Dosimetry for Children (5 year old)

Radiopharmaceutical	Administered activity MBq (mCi)	Organ receiving the largest radiation dose mGy per MBq (rad per mCi)	Effective dose mSv per MBq (rem per mCi)
Tc-99m labeled red blood cells[1]	7 – 15 i.v. (0.2 – 0.4)	0.062 Heart (0.23)	0.025 (0.093)
Tc-99m albumin[2]	5 – 10 i.v. (0.1 – 0.3)	0.054 Heart (0.23)	0.023 (0.085)

[1]ICRP 53, p. 210
[2]ICRP 53, p. 173

dose is excreted in the urine in the first 24 hours. A stannous pyrophosphate preparation is typically used in most red cell labeling techniques. The dosage of this preparation may need to be increased in patients receiving "full-dose" heparin and in patients in renal failure.

Labeling is least consistent with the in vivo method, intermediate with the modified in vivo method, and most consistent with the in vitro method. Tc-99m–radiolabeled human serum albumin (HSA) is an alternative to radiolabeled RBCs. However, images are usually of lower quality because of the escape of tracer from the intravascular space and breakdown of the albumin, resulting in decreased contrast.

E. Image Acquisition
   1. Rest study
      a. Instrumentation
         Acquisition is performed by a gamma camera interfaced to a dedicated computer. Images may be acquired with either a low-energy all-purpose (LEAP) or high-resolution parallel-hole collimator. An appropriate ECG gating device should interface with the acquisition computer. The simultaneity of the gating device's R-wave trigger and the patient's QRS complex should be verified before initiation of the study. An appropriate R-R interval beat acceptance window should be selected to account for heart rate variability and ectopy. Systolic function determinations are less susceptible to heart rate variability than diastolic function measurements. "List" mode acquisition is useful for making a composite cardiac cycle from a heterogenous population of beats and for retrograde gating for diastolic parameters.
      b. Acquisition parameters
         A minimum of 16 frames per R-R interval are required for an accurate assessment of ventricular wall motion and assessment of ejection fraction. A higher framing rate (32–64 frames per R-R) is preferred for detailed measurement of diastolic filling parameters and is required for absolute volume measurements. Acceptable indices of diastolic function are achievable at 16 frames per cardiac cycle, if Fourier curve fitting is employed.

         Images should be acquired so that the heart occupies ~50% of the usable field of view. Typical acquisitions are for a total of 3–7 million counts. Supine imaging is performed in a minimum of 3 views to visualize all wall segments of the left ventricle. The left anterior oblique (LAO) acquisition is obtained at 45° or at an angle that allows the best separation of the right and left ventricles (best septal or best separation view). An anterior acquisition is obtained in a straight (0°) anterior projection or at an angle ~45° less than the "best septal" view. The lateral acquisition is obtained as a left cross-table lateral or at an angle that is approximately 45° greater than the best septal view. The lateral view may also be acquired in the right-side-down left lateral decubitus position. This altered positioning may improve visualization of the true posterobasal segment.

A 70° LAO acquisition may be used instead of a left cross-table lateral view. Left posterior oblique (LPO) or right anterior oblique (RAO) acquisitions may be of additional benefit. These angles often need to be altered in patients with congenital heart or lung anomalies or right-sided overload. A slant-hole collimator may be used for angulation in the caudal–cephalic plane to help separate the ventricles from the atria.

2. Stress study
   a. Instrumentation
      Refer to IV.E.1.a in this guideline. A high sensitivity or LEAP collimator is preferred for the stress equilibrium study.
   b. Acquisition parameters
      Refer to IV.E.1.b in this guideline. Sixteen frames per R-R interval are sufficient for assessment of ventricular wall motion and LVEF. SPECT imaging with 8 or 16 frames is an acceptable substitute. Images may be acquired on a bicycle ergometer in either a supine, semiupright, or upright position using the best septal view as previously described or other views as appropriate to visualize a specific region of interest (ROI). The most accurate determination of the LVEF is usually obtained in the best septal view.

      Images may be acquired at multiple levels of exercise. A 2–3-minute acquisition may be attained at each new level of exercise once a stable heart rate is attained (usually beginning after 1 minute of exercise at the new level). The last stage of exercise may be extended to increase image statistics, but workload should not be decreased. A postexercise RVG is desirable to assess postexercise recovery; LVEF increases promptly in the great majority of patients.

      Pharmacologic stress with inotropic agents, mental stress, and atrial or ventricular pacing are other, less common alternatives to exercise testing.

F. Interventions
   Mental stress studies or pharmacologic stress as well as pacing are potential interventions in patients who cannot exercise.

G. Processing
   The cine loop should be reviewed for adequacy of counting statistics, appropriate ECG gating, adequacy of radiopharmaceutical labeling, and positioning of the heart. A subjective visual assessment of left ventricular systolic function should be performed before calculation of LVEF. ROIs should be created, either manually by the operator or automatically by the computer, so that all activity from the left ventricle is encompassed by the ROI. The ROI used for background correction should be free of activity from the spleen or descending aorta. Other ventricular systolic and diastolic parameters may be generated. Discrepancies between the calculated LVEF and qualitative left ventricular systolic function should be resolved by reprocessing, when necessary. Ventricular volumes may be calculated using either count-based or geometric methods. Calculation of the stroke volume ratio may be helpful in patients suspected of valvular disease. Spatial and temporal filtering may be used, if desired, to enhance visual appearance of the images. Parametric images (e.g., phase/amplitude images) may also aid in image interpretation.

H. Interpretation Criteria
   1. Cardiac morphology
      The morphology, orientation, and sizes of the cardiac chambers and great vessels should be evaluated subjectively and reported. The thickness of the pericardial silhouette and the ventricular wall may also be evaluated subjectively and reported. When measured, absolute ventricular volumes may also be included, although measurements of absolute ventricular volumes by planar images are problematic. SPECT measurements will be more reliable. Automated programs to calculate ejection fraction and volumes are preferable for gated SPECT.
   2. Systolic ventricular function
      Global left ventricular function should be assessed qualitatively and compared with the calculated ejection fraction. Discrepancies should be resolved by reprocessing, when necessary. Normal values for LVEF range between ~50% and 80% at rest and between 56% and 86% at stress. All left ventricular segments should be assessed for regional function using cinematic display of each view. Abnormalities of contraction should be described using the conventional terms of mild, moderate, or severe hypokinesia, akinesia, and dyskinesia. Systematic reporting may be aided by standardized recording forms. Parametric images, such as phase and amplitude images, may be useful in evaluating regional variations in the timing and magnitude of contraction, identifying valve planes, and identification of conduction abnormalities. The pattern of left ventricular

diastolic function may be evaluated qualitatively from the volume curve and reported with quantitative measurements. One can adjust for differences that result from heart rate or systolic function by dividing filling rate by emptying rate. Right ventricular systolic function may be approximated by calculation of RVEF; however, more accurate determination may require a different technique, such as first-pass RNA. Normal values for RVEF range between ~46% and 70%.

3. Stress images
   The stress or intervention study should be displayed side-by-side with the resting study in cinematic mode. Changes in chamber sizes, regional wall motion, and global ejection fraction of both ventricles should be addressed qualitatively and reported with quantitative measures of ejection fraction.
4. Comparison with previous studies
   Results should be compared with any previous studies by direct comparison of the cinematic displays of the two studies, whenever possible. Discrepancies should be resolved by reprocessing when necessary.

I. Reporting
   1. Procedures and materials
      Reporting of the method of ECG gating (forward only, buffered beat averaging), beat acceptance/rejection, and underlying cardiac rhythm is optional. Type and dose of radiolabeling (Tc-99m RBCs in vivo, modified in vivo, in vitro; Tc-99m HSA) and views obtained should be reported.
   2. Findings
      a. Cardiac morphology
         Comment on size of various cardiac chambers, ventricular wall thickness and pericardial silhouette.
      b. Systolic function
         i. Report global LVEF.
         ii. Report regional left ventricular wall motion.
         iii. Option: report global RVEF.
         iv. Option: report diastolic filling indices.
         v. Option: report systolic emptying indices.
      c. Stress images
         i. Report baseline, peak and recovery LVEF.
         ii. Report any alteration in visually assessed regional wall motion, global left and right ventricular function, and volumes.
         iii. Option: report stress ECG and hemodynamics.
         iv. Option: report left ventricular end-diastolic and end-systolic volume.
         v. Report noncardiac vascular abnormalities (e.g., aortic dilatation).

J. Quality Control
   Please refer to the Society of Nuclear Medicine Procedure Guideline for General Imaging.

K. Sources of Error
   1. RBC labeling
      Certain medications and disease processes (e.g., chronic renal failure) will decrease labeling efficiency and reduce the target-to-background ratio.
   2. Patient positioning
      The ejection fraction may be inaccurately calculated by inadequate separation of the left ventricle from other cardiac structures, especially the left atrium (which has a time–activity curve that is the opposite of that of the left ventricle).
   3. Gating errors
      A poor ECG signal or one in which complexes other than the QRS complex are dominant may result in spurious gating and data that are not interpretable. Care should be taken to ensure that the QRS complex is the triggering signal (e.g., choosing an ECG lead in which the QRS is much larger than the T wave). The best gating can be obtained from systems that compute the rate of change of voltage on the ECG to be sure that the QRS and not the T wave is the signal used.
   4. Heart rate variability
      Significant heart rate variability may compromise the determination of diastolic filling indices.
   5. Image statistics
      Inadequate counts/frame may compromise image interpretation as well as decrease the statistical reliability of quantitative measurements.
   6. Processing errors
      Inclusion of nonventricular activity or exclusion of ventricular activity from ventricular ROIs may cause underestimation or overestimation of the ejection fraction. Including the left atrium in the ROI my also alter the LVEF. Inclusion of structures such as the spleen or the descending aorta in the background ROI may alter the LVEF.

V. Issues Requiring Further Clarification

None

VI. Concise Bibliography

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VII. Disclaimer

The Society of Nuclear Medicine has written and approved guidelines to promote the cost-effective use of high quality nuclear medicine procedures. These generic recommendations cannot be applied to all patients in all practice settings. The guidelines should not be deemed inclusive of all proper procedures or exclusive of other procedures rea-

sonably directed to obtaining the same results. The spectrum of patients seen in a specialized practice setting may be quite different than the spectrum of patients seen in a more general practice setting. The appropriateness of a procedure will depend in part on the prevalence of disease in the patient population. In addition, the resources available to care for patients may vary greatly from one medical facility to another. For these reasons, guidelines cannot be rigidly applied.

Advances in medicine occur at a rapid rate. The date of a guideline should always be considered in determining its current applicability.