Imaging

Gated First-Pass RVEF as a Routine Procedure with Cardiac Studies

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Evaluation of right ventricular function has proven to be a valuable tool in assessment of a variety of cardiac and noncardiac diseases. First-pass right ventricular studies can be easily performed with a multicrystal camera. For nuclear medicine departments with a single crystal camera, however, first-pass right ventricular studies become more difficult. We describe how the single crystal camera can be used to perform gated first-pass radionuclide angiocardiograms, a simple and effective way to determine right ventricular ejection fraction. The validity of such a first-pass study depends primarily on the administration of a compact radionuclide bolus. We have developed a simple method for bolus delivery, using the external jugular vein as the injection site. Our method, including data analysis, can be easily incorporated into routine multiple gated equilibrium cardiac studies.

Analysis of right ventricular function is useful in the evaluation of patients with valvular heart disease, coronary artery disease, congenital heart disease, and obstructive airway disease. It is performed easily using the first-pass technique and a multicrystal camera. Because of count rate limitations, the first-pass technique is generally not used with a single crystal camera. Instead, departments with a single crystal camera usually determine the right ventricular ejection fraction (RVEF) using the equilibrium gated technique (*1–3*). This presents problems because of overlap of right and left ventricles.

First-pass gated radionuclide angiocardiography provides a technique for measuring RVEF using a single crystal camera (*4, 5*). This allows spatial and temporal separation of the right ventricle from the other cardiac chambers and cinematic display of right ventricular motion. We have devised a simple technique for performing first-pass gated radionuclide angiocardiograms using commercially available software.

Materials and Methods

Preparation for the study is two-fold. First, the patient is given an intravenous injection of 5–15 mg of "cold" stannous pyrophosphate approximately 30 min before the start of the examination. Then we thoroughly explain the exam to the patient, especially the use of a neck vein as the injection site. The importance of central venous injection to obtain the best possible study is emphasized and the patient is reassured that the introduction of an intravenous line into the external jugular vein is a safe and relatively harmless procedure.

Because we perform a gated first-pass study, we use an ECG monitor (Medical Electronics Corp., Boston, MA) and standard three-lead electrode placement. The patient lies supine with ECG electrodes in place. Before the positioning under the camera, the patient's head is turned to the left, thereby exposing the external jugular vein. Venous anatomy calls for use of the right external jugular vein; however, the left external jugular vein will suffice, as will an antecubital vein if necessary.

The injection site is prepared with a Betadine swab, and a 21-gauge butterfly needle with 12-in. tubing is introduced into the vein. A syringe containing 5–10 cc normal saline is attached to the end of the tubing and is used to establish and maintain the patency of the line prior to addition of the bolus injection unit. Our bolus injection unit consists of a valve check unit (Paramedical Inc., Watertown, MA), which is essentially a one-way valve with three openings. A syringe containing 10-cc normal saline is attached to one end of the unit while the opposite end is inserted into the luer lock of the butterfly infusion set. The third injection port is used to introduce the radionuclide into the line.

The patient is now ready to be positioned under the camera head. The anterior position, with a 10° caudal tilt, provides adequate separation of the right ventricle from the right atrium and allows for optimal visualization of cardiac hemodynamics (Fig. 1). We use an upgraded single crystal gamma camera (MEDX, Palatine, IL) with a low-energy, all-purpose collimator and a dedicated mobile computer (MDS A^2, Ann Arbor, MI). Data acquisition is done in the list mode with ECG trigger and follows the protocol outlined in the MDS operators' manual (*6*).

With the patient positioned and the camera ready for list

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mode acquisition, a dose of 20–25 mCi of [^{99m}Tc] pertechnetate in 0.3–0.5 ml is delivered through the injection port of the valve check unit. We follow this order: start saline flush; start computer; push [^{99m}Tc] pertechnetate; finish saline flush; and stop acquisition with appearance of left ventricle on the persistence scope.

Total acquisition time ranges from 10–15 sec. The routine anterior and LAO multiple gated equilibrium images are then acquired.

Delivery of a compact bolus is essential; therefore, if the patient appears nervous, we allow a few minutes between IV placement and injection. This reduces the likelihood of a valsalva response and assures stability of the patient's heart rate (necessary for a gated study). We have found verbal signals to be detrimental, since they may make the patient anxious.

Prior to determining RVEF, the first-pass list mode data are reformatted into 14 (64 × 64 byte) frames, using the maximum time per frame allowed by the computer. For maximum accuracy in volume curve determination, the data are reformatted in two directions, forward and backward. Reformatting in the forward direction produces a curve demonstrating the first third of the volume curve, i.e., the rate of cardiac emptying, while the backward curve represents the cardiac filling phase. The computer creates two studies, multiplies each study by a weighting coefficient, and then adds the two together. The resultant study includes the best features of both curves and also serves to smooth the study data (*6*).

In list-mode acquisition, the computer stores "R-wave markers" in sequence with the X and Y coordinates of each scintillation event. During reformatting, the computer automatically constructs a histogram of all heart cycles for the duration of the acquisition. The technologist inspects the R-R interval histogram and chooses R-R limits to exclude any ectopic beats that have occurred during acquisition. To assess right ventricular function, heart cycles corresponding to peak right ventricular activity are chosen. Cursors are positioned at two points corresponding to entrance of the bolus into the right heart and visualization of the lungs. By noting the numbers of the R-R limits selected, and observing the resultant images as they are reconstructed on the computer terminal, the operator can determine whether the selected interval satisfactorily represents the flow of activity through the right heart and lungs. If not, the procedure is terminated manually, and the reformatting process is repeated, changing the positions of the cursors.

(Another method for selecting the R-R limits requires the operator to reformat the data into a dynamic study, then select the time interval corresponding to peak right ventricular activity by watching a display of the series of images created. We have found, however, that this method consumes more time and disk space.) The final reformatted gated study is filtered both spatially and temporally (Fig. 2).

The RVEF is determined using a standard program for edge detection. This program involves placement of a rectangular "box" around the right ventricle, avoiding the right atrium and pulmonary artery. The technologist is allowed to create the best "fit." Cinematic display of the filtered images, as well as phase analysis of the reformatted study, is helpful in determining the limits of the right ventricle before the box is positioned (Fig. 3).

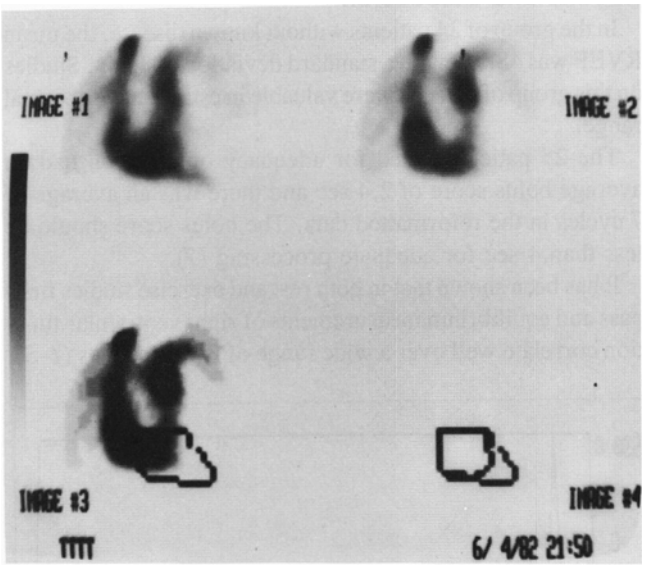

FIG. 2. (1) ED frame; (2) ES frame; (3) and (4) overlayed edges.

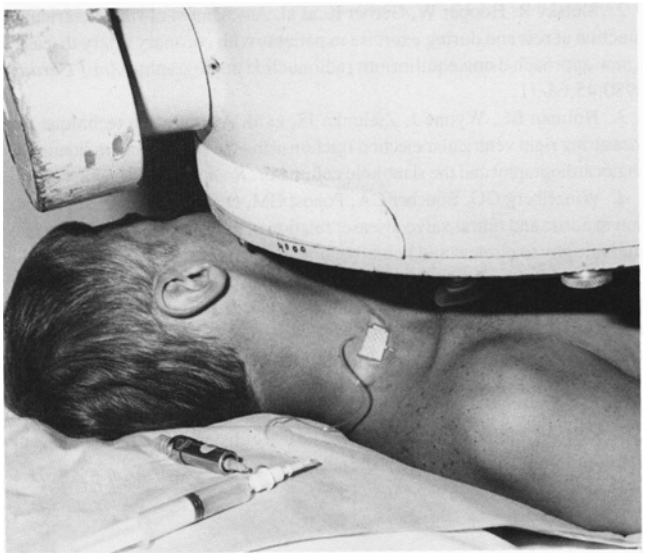

FIG. 1. Patient positioned and ready for injection.

The number of cardiac cycles available for reformatting depends on the quality of the injection. The compactness of the injection is determined by finding the "bolus score" (*7*) from a superior vena cava (SVC) time-activity curve. This curve is generated after reformatting the data as a dynamic study. The bolus score is the time between 10% of maximal activity on the upslope of the SVC curve and 25% of maximal activity on the downslope (Fig. 4).

Patient groups were selected to establish normal RVEFs and to test the injection technique. Right ventricular ejection fractions were evaluated in a group of 34 patients without known heart or lung diseases. These patients were referred

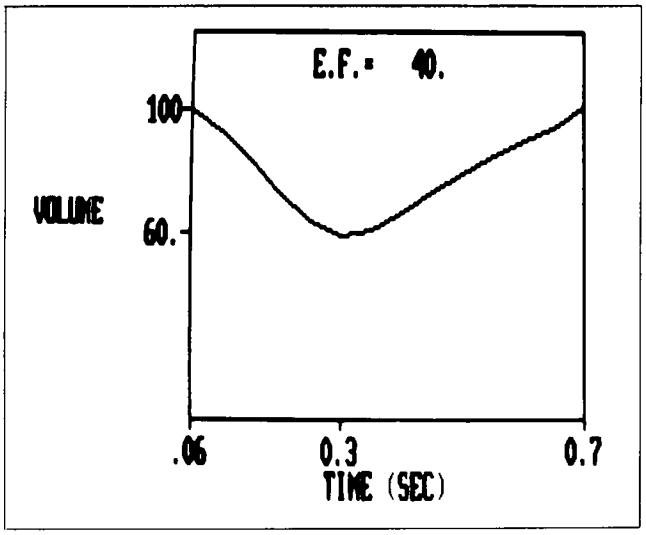

FIG. 3. RVEF curve.

for prechemotherapy ejection fraction evaluations, preoperative evaluations, etc. Another group of 25 patients was tested for adequacy of the injection.

Results and Discussion

In the group of 34 patients without known disease, the mean RVEF was 48.9% with a standard deviation of 8.6%. Studies on this group of patients were valuable in establishing a normal range.

The 25 patients tested for adequacy of injection had an average bolus score of 2.4 sec and there was an average of 7 cycles in the reformatted data. The bolus score should be less than 4 sec for adequate processing (*7*).

It has been shown that in both rest and exercise studies first-pass and equilibrium measurements of right ventricular function correlate well over a wide range of RVEF values (*1–3*).

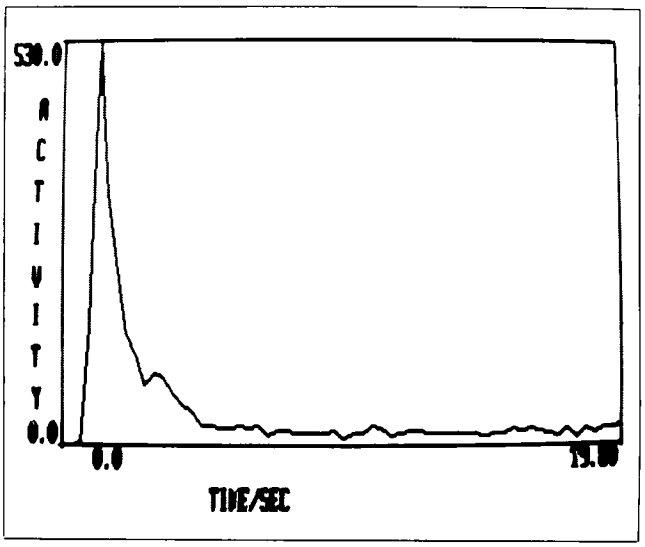

FIG. 4. Superior vena cava time-activity curve.

The first-pass study eliminates the problem of superimposition of cardiac chambers encountered with right ventricle equilibrium studies and provides a higher target-to-background count ratio. Because right and left ventricular activity is temporally separated, the right ventricle may be viewed in any projection. In addition, the first-pass study requires considerably less acquisition time than the equilibrium study: 10–15 sec versus 7–10 min per equilibrium view (*8*).

The gated first-pass technique allows evaluation of right ventricular function as easily as the nongated technique. Further, it allows use of the single crystal camera (*4*). List mode acquisition allows the operator to choose the R-R limits for reformatting. This method has two distinct advantages. First, any ectopic beats occurring during acquisition may be manually excluded. Second, the operator can select the time interval, and therefore the region of interest, to be studied by selecting time limits corresponding to maximum region activity (*8*).

Since the resulting study is processed as an equilibrium study, a varying region of interest can be used to determine the RVEF. The nongated technique allows for fixed regions of interest only; first-pass and equilibrium measurement of RVEF have proven to be less satisfactory with a fixed region of interest than with a variable one (*3*).

Of the various methods available, we find our bolus injection unit to be the simplest and easiest. It minimizes the radiation dose to the technologist and reduces the possibility of radionuclide contamination.

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