Imaging

Quantitative Evaluation of Cardiac Volumes and Outputs: Technical Aspects

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In addition to the ejection fractions and wall motion evaluations reported through conventional equilibrium gated blood pool scans, left ventricular volumes and cardiac output values may also be obtained. We describe a cardiac function study based on a model of the kinetics of a bolus of technetium-99m-labeled red cells through the left ventricle (1). Data acquisition requires only a slight modification of the conventional gated procedure. The method described has become a valuable adjunct to conventional radionuclide procedures for evaluation of left ventricular function at our institution.

Recent literature describes a model for the kinetics of labeled red cells through the left ventricle (*1*). The model was then used to determine left ventricular volumes. Data acquisition of the proposed technique consisted of the following steps: (1) Red blood cells were obtained from a patient, labeled with technetium-99m in vitro, and reinjected as a bolus into an anticubital vein. Dynamic images of the bolus of activity through the left ventricle were recorded in the 45° left anterior oblique (LAO) view. (2) After mixing the labeled cells with the blood pool, an equilibrium gated blood pool scan was recorded also in the 45° LAO view. (3) A blood sample was then obtained from the patient and its specific activity determined.

Data analysis consisted of the following: (1) A time-activity curve over the left ventricle was constructed from the dynamic study and the area under the curve measured. This area was modified using the patient's heart rate and ejection fraction. The activity of the bolus, which is numerically equal to the count rate that would be observed if all injected activity were stationary in the left ventricle, was obtained. (2) Count rates from the left ventricle were obtained from the gated study in frames corresponding to end-diastole and end-systole. When these count rates were divided by the activity of the bolus, left ventricular volumes expressed as percentages of the total blood volume were obtained. (3) The total blood volume was found by dividing the total injected activity by the specific activity of the blood pool. (4) The left ventricular volume in absolute terms was obtained by multiplying left ventricular volume percentage by total blood volume. In addition to the end-diastolic and end-systolic volume determinations described in the literature (*1*), the cardiac output may also be determined by multiplying the difference between the diastolic and systolic volumes by the heart rate.

What follows are technical details of data acquisition and analysis for this new procedure presented in a step-by-step manner for a typical patient enountered in our department for this study.

Methods

Injected Activity: Approximately 20 mCi of Tc-99m pertechnetate solution obtained from a generator is placed into a 5-ml syringe. The syringe is weighed before and after the addition of technetium and the difference is taken as the weight of the technetium solution. A 100:1 dilution of the technetium solution (e.g., 0.1-ml pertechnetate in 9.9-ml sterile saline) is also produced, and a similar volume is drawn into a weighed syringe. This is placed on the collimator face of the gamma camera, and several 1-sec counts are recorded for different positions of the syringe on the collimator face. The specific activity of the undiluted technetium solution is determined by multiplying the average count rate by 100 and dividing by the weight of diluted technetium solution in the syringe. For example, if the averaged count rate for a syringe containing 1.34 g of 100:1 dilution of Tc-99 solution in 1,250 counts/sec, then:

$$\text{specific activity} = \frac{1{,}250 \text{ counts/sec} \times 100}{1.34}$$
$$= 93{,}284 \text{ counts/g-sec.}$$

If the weight of technetium in the injection syringe is 1.45 g, the activity of the solution is 93,284 counts/g-sec × 1.45 g or 135,262 counts/sec. The activity in the injection syringe is

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decayed to the time of injection. For example, if the activity determination is made 45 min before injection, the activity in the syringe at the time of injection is $135{,}262 \times e^{-0.1155 \times 45/60}$ or 124,036 counts/sec. Some activity remains in the patient's syringe after injection and this should be subtracted from the above expression to determine the total injected activity. In the present case, the injection syringe was found to have 4,120 counts/sec remaining 80 min after injection. Correcting this to the time of injection gives $4{,}120 \times e^{-0.1155 \times 80/60}$ or 4,806 counts/sec. The total injected activity is, therefore, 124,036 − 4,806 or 119,220 counts/sec.

Patient Preparation: The patient receives an intravenous injection of 1.5 ml of a stannous pyrophosphate solution approximately 20 min before the procedure. Next, the injection syringe is connected to a butterfly catheter with a three-way stopcock. The needle is placed into an antecubital vein and the catheter is flushed with 5U/ml solution of heparinized sterile normal saline. Then approximately 3 ml of venous blood is drawn into the injection syringe, which contains 20-mCi pertechnetate. The syringe is inverted one time/min and the blood is allowed to mix with the technetium solution for approximately 10 min in accordance with the "in vivo-in vitro" red cell labeling technique (*2*).

Data Collection: The supine patient is placed under a standard field scintillation camera; a general all-purpose collimator is in the 45° LAO position over the patient's chest. The camera is interfaced to a standard nuclear medicine computer. The energy window setting is 15% and the "zoom" feature is turned off. The computer is set for a 120 frame, 64 × 64 byte mode, dynamic scan with one frame/sec. The labeled red cells are injected and a dynamic scan of the bolus of red cells through the left ventricle is recorded. After the dynamic scan and before any change in patient/detector geometry is made, a short (approximately 2 min) gated blood pool scan is acquired for a fixed number of cardiac cycles (e.g., 200 cycles) and a specified time per frame (e.g., 0.05 sec). After the gated blood pool scan is obtained, a small sample of venous blood is drawn into a weighed syringe.

Data Analysis

Blood Volume: The syringe containing the sample of venous blood is placed at various positions on the collimator face and counted for 100 sec in each position. The averaged counts are corrected for background, divided by the weight of blood in the syringe, multiplied by the specific gravity of blood (1.06 g/ml) and decay corrected to time of injection. In the present case the counts/100 sec for 2.2 g of blood 1-hr postinjection is 4,012. The corrected count rate is:

$$4{,}012 \times \frac{1}{100} \times \frac{1}{2.2} \times 1.06 \times e^{+0.1155 \times 60/60} = 21.7 \text{ counts/ml-sec.}$$

The total blood volume in the present case is:

$$\frac{119{,}220 \text{ counts/sec}}{21.7 \text{ counts/ml-sec}} = 5{,}494 \text{ ml.}$$

Left Ventricular Volumes: Regions of interest are drawn around the left ventricle in the multigated frames corresponding to end-diastole and end-systole (Fig. 1A and B). The observed count rates in these regions of interest are corrected for background (using counts/pixel in the background region of Fig. 1C). In the present case, diastolic counts = 10,880; systolic counts = 6,750.

The ejection fraction is thus determined to be (10,880 − 6,750)/10,880 or 0.38. The diastolic and systolic counts are corrected for time/frame and for the number of cardiac cycles superimposed during the scan (*3,4*). In the present case, the time/frame is 0.05 sec and 200 cardiac cycles are superimposed; thus:

$$\text{diastolic count rate} = 10{,}880 \times \frac{1}{200} \times \frac{1}{0.05} = 1{,}088 \text{ counts/sec.}$$

and

$$\text{systolic count rate} = 6{,}750 \times \frac{1}{200} \times \frac{1}{0.05} = 675 \text{ counts/sec.}$$

A region of interest is drawn around the left ventricle frame in the dynamic phase of the study (Fig. 2A) and a time-activity curve of the bolus of red cells passing through the left ventricle is obtained (Fig. 2B). The ascending and descending regions of the curve are fitted to a gamma variate function. This gamma variate curve is then integrated. The area under the curve yields the total counts recorded in the left ventricle as the bolus of activity passes. In the present case the total counts are 64,500. The count rate that would have been observed if all injected activity had been stationary in the left ventricle, i.e., the activity of bolus (*1*), is given by

$$\text{activity of bolus} = \frac{\text{heart rate}}{60} \times \frac{2 \times \text{ejection fraction}}{2 - \text{ejection fraction}} \times (\text{total counts}).$$

In the present case, the heart rate at the time of injection is 88 beats/min; thus,

$$\text{activity of bolus} = \frac{88}{60} \times \frac{2 \times 0.38}{2 - 0.38} \times 64{,}500 = 44{,}303 \text{ counts/sec.}$$

Left ventricular volumes expressed as percentages of total blood volume are obtained by dividing the diastolic and systolic count rates by the activity of the bolus.

diastolic volume % = 1,088/44,303 × 100% = 2.46%.

systolic volume % = 675/44,303 × 100% = 1.52%.

The absolute left ventricular volume is obtained by multiplying these percentages by the known total blood volume:

diastolic volume = 5,494 × 0.0246 = 135 ml.

systolic volume = 5,494 × 0.0152 = 84 ml.

Stroke volume is simply the difference of the end-diastolic and end-systolic volumes. Cardiac output is determined by multiplying the stroke volume by the heart rate. In the present case:

cardiac output = 88 × (135 − 84) = 4,488 ml/min.

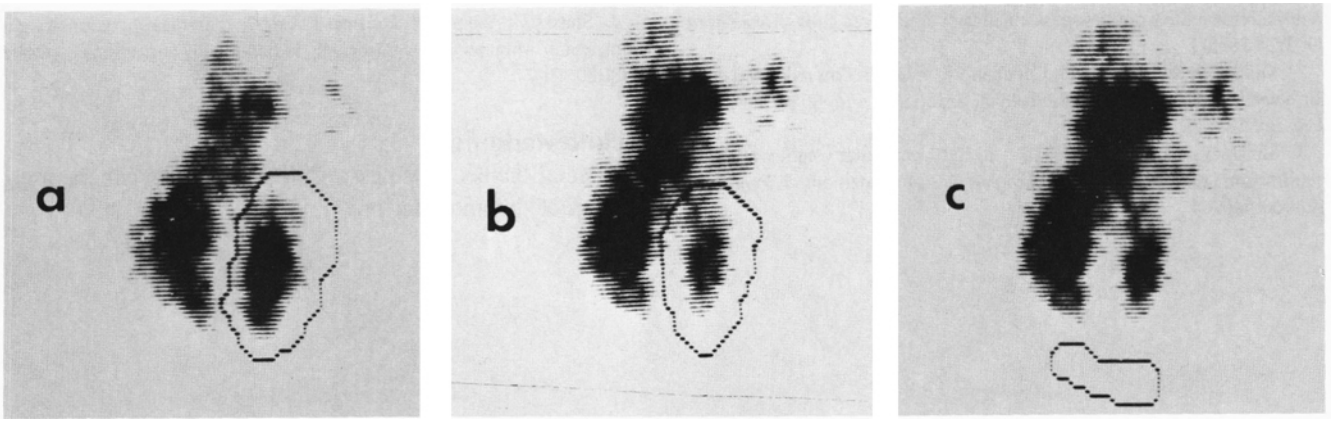

FIG. 1. Regions of interest for determination of (A) end-diastolic, (B) end-systolic, and (C) background count rates for gated portion of study.

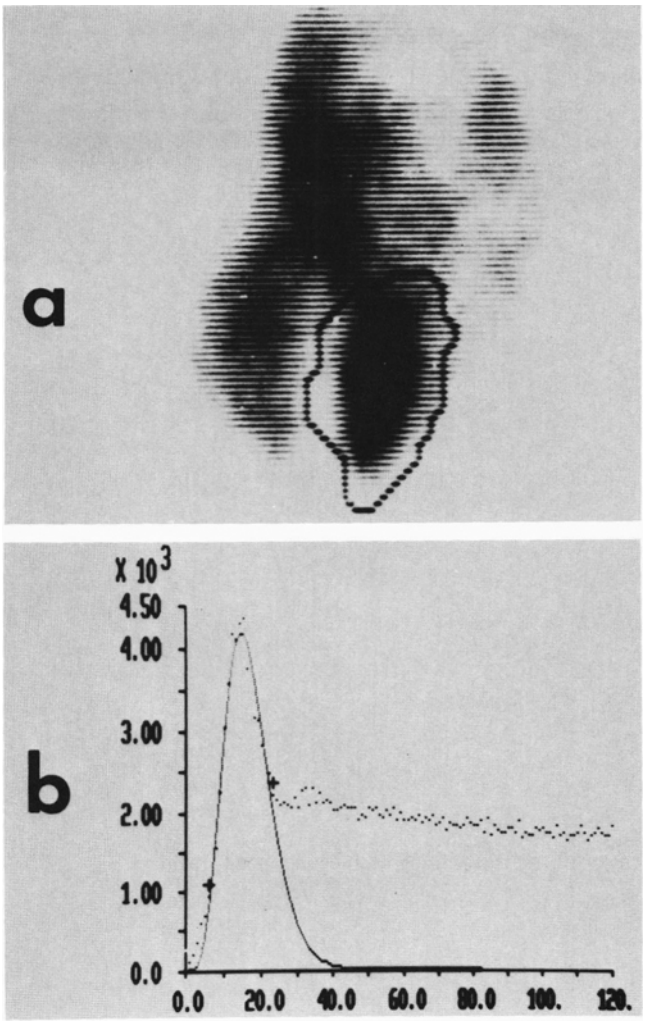

FIG. 2. (A). Regions of interest for the generation of the left ventricular time-activity curve. (B). Time-activity curve for bolus of labeled red cells through left ventricle and gamma variate curve fit.

Discussion

This radionuclide technique expresses left ventricular volumes as the product of two logically separate factors: the left ventricular volume percentage and the total blood volume. The left ventricular volume percentages are determined by dividing count rates obtained in a region of interest drawn around the left ventricle in the gated phase of the study by a count rate obtained from a similar region of interest during the first pass phase of the study. Since both count rates may be assumed to have experienced the same degree of attenuation, the resulting ratio is independent of attenuation.

The other factor is the total blood volume, which is obtained by dividing the injected activity by the specific activity of the blood pool. Errors introduced in measuring the syringe weight or in pipetting the pertechnetate standard will affect the calculated value of the total blood volume. Since left ventricular volume is directly proportional to the total blood volume, a 10% error in total blood volume, for example, will be reflected in a 10% error in the calculated value of left ventricular volume. There is, however, no magnification of error because of weighing or pipetting.

Left ventricular volume determinations made by the method described have been shown to correlate well with those made by contrast left ventriculography in patients suffering from nonvalvular heart disease (*1*). End-systolic volumes were found to range from 29–240 ml and end-diastolic volumes ranged from 94–370 ml. Furthermore, cardiac output determinations made by our method have been found to correlate well with those made by the temperature dilution method in a group of patients with no right-sided valvular disease.

We believe considerably more information may be obtained from the typical cardiac gated blood pool scan than is obtained in most situations. Certainly, the accurate determination of such parameters as cardiac output and stroke volume in a noninvasive manner represents a valuable service for many physicians and their patients. The method we describe represents a relatively quick and easy method to obtain these important parameters of cardiac function with only slight modification of the routine radionuclide ventriculogram. This information may be obtained using a standard gamma camera with a typical nuclear medicine computer and existing computer software. The data obtained with this technique may prove valuable in patient management without the inherently higher risk of obtaining this information with cardiac catheterization.

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ventricular volume from first-pass kinetics of labeled red cells. *J Nucl Med* 1983;24:98–103.

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