

Absolute Left Ventricular Volume Using the Build Up Factor

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A new method for determining absolute left ventricular (LV) volumes from radionuclide gated blood pool images has been validated at our institution (1). Only four parameters are needed to determine LV volumes: the LV count rates from an LAO and an RPO image (180° opposed to the LAO), a venous blood sample, and a patient thickness measurement. The procedure can easily be performed as a part of routine gated blood pool imaging. The technique is non-geometric, corrects for tissue attenuation, and uses an experimentally determined build up factor to account for the effects of scatter.

The ability to accurately measure absolute LV volumes is of great clinical importance (1). Contrast ventriculography has been the most widely used method for measurement of LV volume. This technique, however, is invasive and requires that geometric assumptions be made regarding the shape of the ventricle (2).

We have recently developed a new technique for measuring absolute ventricular volumes during gated blood pool imaging based upon the use of the build up factor (1). The build up factor accounts for the increased count rate due to scatter which occurs as a result of the broad-beam geometry inherent in clinical nuclear medicine imaging (3). The method involves the following steps:

1. Count rates from left anterior oblique (C_{LAO}) and right posterior oblique (C_{RPO}) [180° opposed from the LAO] images of the LV at end diastole, are obtained using a parallel hole collimator (Fig. 1). Count rates at end systole for each projection, C'_{LAO} and C'_{RPO} , are obtained by multiplying the respective count rate at end diastole by (1-EF). The ejection fraction is obtained in the conventional manner using a semi-automated computer program. C'_{LAO} can also be determined by direct measurement of the end-systolic image.

2. Measure the total patient thickness (T) in cm obliquely from the LAO to RPO view (Fig. 1).

3. The following equation for C_o is solved (Appendix):
$$C_o = \exp [(\ln C_{LAO} + \ln C_{RPO} - 2 \ln 1.24 + 0.13 T)/2]$$
 (1) where C_o is the count rate (counts per second) of the LV corrected for attenuation, C_{LAO} is the LAO count rate (counts per second) from the LV, C_{RPO} is the RPO count rate (counts per second) from the LV, 1.24 is the constant build up factor obtained in a phantom of tissue equivalent material, and 0.13 cm^{-1} is the linear attenuation coefficient measured in the same phantom. The build up factor and linear attenuation coefficient will vary from camera to camera and therefore, must be determined for each individual system.

4. A blood sample count rate per ml, C_B , is obtained by withdrawing a 10 ml venous blood sample and counting the sample using the same scintillation camera and collimator used to obtain the LAO and RPO views. The cross sectional area of the LV is approximated by counting the blood in a 10 cm petri dish.

5. The absolute left ventricular volume is then calculated:
End-diastolic volume (EDV) = C_o / C_B (2)

End-systolic volume (ESV) = EDV × (1-EF)

A transmission factor (TF) may also be calculated for comparison with other reported techniques according to the following relationship: $TF = C_{LAO} / C_o$. Determination of the TF is not necessary for LV volume measurement.

Materials and Methods

Thirty-four patients referred for cardiac catheterization were studied. The patient's red blood cells were labeled in vivo with 20–30 mCi of [^{99m}Tc] pertechnetate twenty minutes after intravenous administration of stannous pyrophosphate. The patient was initially positioned prone in front of a scintillation camera to acquire an RPO dynamic first pass radionuclide angiogram. Serial 1 sec images were collected for 60 sec fol-

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lowing the intravenous bolus injection of [^{99m}Tc] pertechnetate. The scintillation camera was peaked for Tc-99m with a 25% window and fitted with a low energy parallel hole collimator. Data was acquired using a standard nuclear medicine computer system. Four to five minutes after injection, RPO gated equilibrium images were acquired in a 64×64 matrix until 300,000 counts were collected in at least one of 16 frames of the cardiac cycle. After completion of the RPO images, the patient was moved to a supine position for LAO images with the collimator viewing the LV 180° from its original RPO position (Fig. 1): This was accomplished by asking the patient to move from the prone to a supine position without moving the collimator. A second equilibrium study was acquired in the LAO projection.

After completion of imaging, a 10 ml venous blood sample was withdrawn into a syringe from a previously unused venipuncture site. The blood sample was immediately emptied into a 100 mm diameter by 15 mm deep petri dish and counted in air at 10 cm from the collimator face of the camera for five minutes. Using calipers, a patient thickness (T) measurement was obtained, corresponding to the LAO to RPO dimension (Fig. 1).

The build up factor is determined using a flat 10 cm source simulating the surface area of the LV containing 1 mCi [^{99m}Tc] pertechnetate. The source was counted in air and at various depths in tissue-equivalent material. This data was then plotted on semilog paper as C/C_0 (y axis) versus depth (x axis) where C is the source count rate measured at various depths in the phantom and C_0 is the source count rate measured in air (Fig. 3). The slope of this line is equal to the linear attenuation coefficient (μ) and the y-intercept is equal to the build up factor (values given in equation 1).

Results

According to equations 1 and 2, only four parameters are necessary for the calculation of LV volumes: C_{LAO} , C_{RPO} , T, and C_b . These variables are discussed below with values given for a typical patient.

LV end-diastolic counts are obtained from the LAO gated blood pool images using a semiautomated computer program

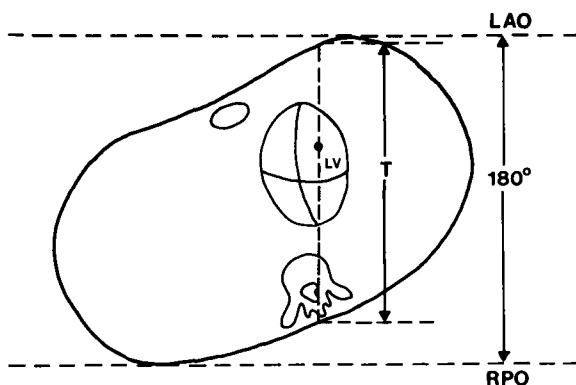


FIG. 1. Schematic representation of the position of the left ventricle (LV) in the left anterior oblique (LAO) and right posterior oblique (RPO) images. T is the patient thickness needed for equation 1.

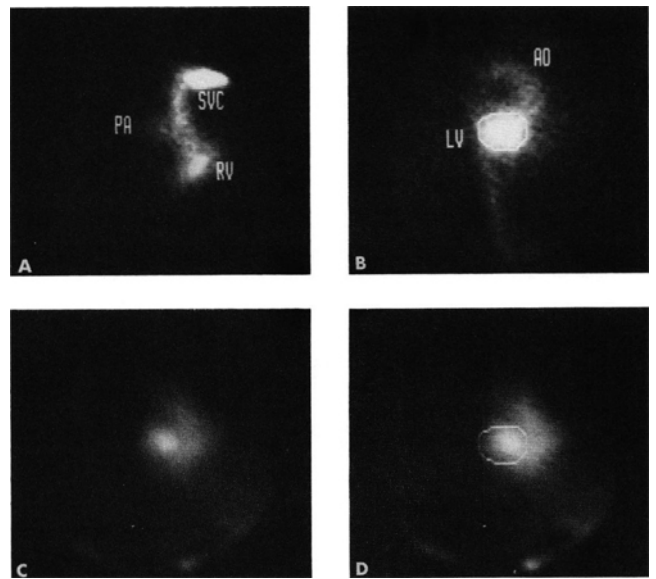


FIG. 2. First pass and equilibrium RPO images. The first pass images are obtained by summing 0.5 second serial images. (A) Right heart phase of the first pass. Activity can be seen in the superior vena cava (SVC), the right ventricle (RV), and the pulmonary artery (PA). (B) Left heart phase of the first pass. This image is used to most easily identify the left ventricular (LV) region of interest. The aorta (AO) can be seen. (C) Equilibrium RPO image. LV and RV activity are shown with the patient in the same position used to acquire the first pass study. (D) Equilibrium RPO image. The first pass LV ROI is superimposed to demonstrate the separation of the ventricle in this view.

(MUGE, Medical Data Systems, Ann Arbor) which generates a region of interest (ROI) around the LV based on a combination second derivative and count threshold algorithm (4). These end diastolic counts are then corrected for background using a ROI adjacent to the LV. The total time for acquisition is derived from the average time per frame multiplied by the number of cardiac cycles acquired. The background corrected end-diastolic counts divided by the total acquisition time yields the net LV count rate at end diastole, C_{LAO} , (equation 1). For a typical patient, the net LV end-diastolic count was 12760, time/frame was 0.05 sec with 343 cardiac cycles accumulated, yielding $C_{\text{LAO}} = 12760/(0.5 \times 343) = 744$ counts/sec.

Background corrected diastolic counts are obtained from the RPO gated blood pool images using a manual ROI around the LV at end diastole. To facilitate identification of the LV in the RPO view, the LV ROI is first identified from the RPO first pass study (Fig. 2). These net end-diastolic counts divided by the total acquisition time yield C_{RPO} , (equation 1).

For the example patient study under consideration, the net LV end-diastolic count in the RPO view was 15803, time/frame was 0.049 sec with 344 cardiac cycles accumulated, resulting in $C_{\text{RPO}} = 15803/(.049 \times 344) = 938$ counts/sec.

The total patient thickness in cm was measured obliquely from the LAO to RPO view and was found to be 32 cm.

Equation 1 can now be solved for C_0 :

$$C_0 = \exp [\ln 744 + \ln 938 - 2 \times \ln 1.24 + 0.13 \times 32]/2]$$

$$C_0 = \exp [(6.61 + 6.84 - 0.43 + 4.16)/2]$$

$$C_0 = \exp [8.59] = 5378 \text{ counts/sec}$$

The 10 ml blood sample count was 71463 for the 300 sec

acquisition. The blood was counted 0.77 hr after the completion of the LAO study and decay correction must be performed. The blood sample count rate per ml, C_B , is

$$C_B = \frac{71463}{(300 \times 10)} \times \exp^{\frac{+693 \times 0.77}{6}}$$

$$C_B = 26 \text{ counts/sec/ml}$$

Equation 2 can now be solved for LV end-diastolic volume (EDV):

$$EDV = 5378/26 = 207 \text{ ml}$$

Knowing the ejection fraction ($EF = 44\%$), the end-systolic volume (ESV) can now be calculated:

$$ESV = 207 \text{ ml} \times (1 - 0.44) = 116 \text{ ml}$$

Absolute left ventricular volumes determined by our method have been shown to correlate well with those made by contrast ventriculography (1). Correlation coefficients of 0.97 for end-diastolic and 0.96 for end-systolic volumes were obtained in our series of 34 patients.

Discussion

The ability to accurately measure left ventricular volumes, particularly at end systole, has recently been shown to be increasingly important for characterizing left ventricular function in valvular heart disease (6) and coronary heart disease (7).

While contrast ventriculography is the most widely used clinical technique for measuring left ventricular volume, it is geometry dependent. The geometric assumptions required about the shape of the left ventricle are frequently invalid, particularly when regional wall motion abnormalities are present and at end systole, when the shape of the left ventricle poorly approximates a standard geometric figure (2). Contrast ventriculography has limited applications when compared to radionuclide methods which are uniquely capable of determining LV volumes at rest and during exercise.

Both geometric- and count-based (8) radionuclide methods have been employed to measure left ventricular volume from equilibrium gated cardiac blood pool imaging. The less precise definition of the edges of the left ventricle in radionuclide studies make probable errors in the geometric technique more likely. Count based methods offer a major advantage since they avoid the need for any geometric assumptions about the shape of the left ventricle. Accurate radionuclide determined volumes do require reliable techniques for edge detection, correction for background activity, attenuation, and scatter. Each of these factors introduces a potential source of error with the radionuclide method.

The first pass RPO study is only useful for identification of the LV in the RPO gated study. Once you have become familiar with locating the LV in this view, the first pass study need no longer be done. The procedure can then be modified as follows: perform the LAO gated study first and then ask the patient to move from the supine to the prone position without moving the collimator to perform the RPO gated study. We have demonstrated that the spinal column does not overlap the LV in this view.

In conclusion, we have developed a new technique for accu-

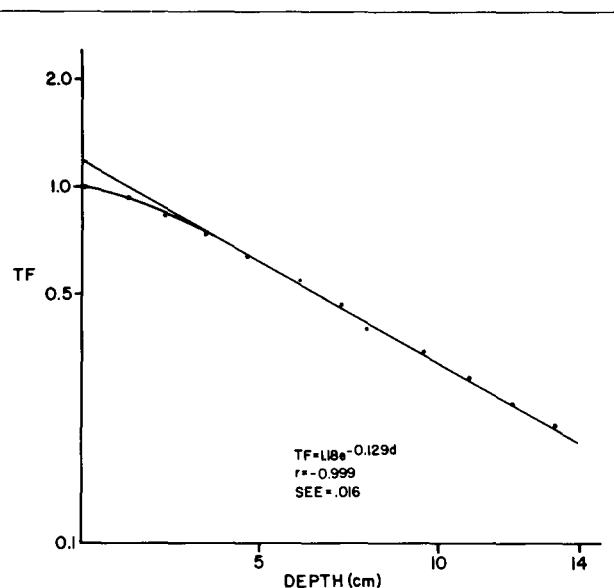


FIG. 3. Transmission factor (TF), given by C/C_0 , as a function of depth obtained in a phantom of tissue-equivalent material.

rate determination of LV volumes from equilibrium gated blood pool imaging. The method corrects for attenuation independent of geometric assumptions. It requires only a blood sample, a patient thickness measurement, and an additional gated RPO view. The procedure can easily be performed as a part of routine gated blood pool imaging once determination of the camera build up factor has been performed.

Appendix

The build-up factor $B(d)$ is given by (1,3)

$$B = (C/C_0) \times e^{\mu d} \quad (A)$$

where C = source count rate measured at various depths in tissue equivalent material,

C_0 = source count rate measured in air,

μ = linear attenuation coefficient in cm^{-1} , and

d = source depth in cm.

Equation A can be rearranged to give

$$C/C_0 = B \times e^{-\mu d} \quad (C)$$

This equation states that a plot of $\ln(C/C_0)$ on the y axis versus depth d on the x axis (semilogarithmic graph) will result in a straight line with a slope equal to the linear attenuation coefficient μ and y intercept equal to a constant build up factor, B . Our data are shown in Figure 3. Using these results, the following two simultaneous equations can now be set up for the left ventricle:

$$C_{LAO} = 1.18 \times C_0 \times e^{-0.13d} \times 1.05 \quad (D)$$

$$C_{RPO} = 1.18 \times C_0 \times e^{-0.13(T-d)} \times 1.05$$

where 1.18 = constant build up factor (intercept of straight line, Figure 3).

0.13 = linear attenuation coefficient (slope of straight line, Figure 3).

1.05 = LV self-attenuation correction (1)

Equation D can be rearranged to solve for C_0 as given by equation 1.

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