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Accurate Estimates of Absolute Left Ventricular Volumes From Equilibrium Radionuclide Angiographic Count Data Using a Simple Geometric Attenuation Correction

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To simplify and clarify the methods of obtaining attenuation-corrected equilibrium radionuclide angiographic estimates of absolute left ventricular volumes, 27 patients who also had biplane contrast cineangiography were evaluated. Background-corrected left ventricular end-diastolic and end-systolic counts were obtained by semiautomated variable and hand-drawn regions of interest and were normalized to cardiac cycles processed, frame rate and blood sample counts. Blood sample counts were acquired on (d°) and at a distance (d′) from the collimator. A simple geometric attenuation correction was performed to obtain absolute left ventricular volume estimates.

Using blood sample counts obtained at d° or d′, the attentuation-corrected radionuclide left ventricular end-diastolic volume estimates using both region of interest selection methods correlated with the cineangiographic end-diastolic volumes ($r = 0.95$ to 0.96). However, both mean radionuclide semiautomated variable left ventricular end-diastolic volumes (179 ± 100 [± 1 standard deviation] and 185 ± 102 ml, $p < 0.001$) were smaller than the average cineangiographic end-diastolic volume (217 ± 102 ml), and both mean hand-drawn left ventricular end-diastolic volumes (212 ± 104 and 220 ± 106 ml) did not differ from the average cineangiographic end-diastolic volume. Using the blood sample counts obtained at d° or d′, the attenuation-corrected radionuclide left ventricular end-systolic volume estimates using both region of interest selection methods correlated with the cineangiographic end-systolic volumes ($r = 0.96$ to 0.98). Also, using blood sample counts at d°, the mean radionuclide semiautomated variable left ventricular end-systolic volume (116 ± 98 ml, $p < 0.05$) was less than the average cineangiographic end-systolic volume (128 ± 98 ml), and the other radionuclide end-systolic volumes did not differ from the average cineangiographic end-systolic volume.

Therefore, it is concluded that: 1) a simple geometric attenuation-correction of radionuclide left ventricular end-diastolic and end-systolic count data provides accurate estimates of biplane cineangiographic end-diastolic and end-systolic volumes; and 2) the hand-drawn region of interest selection method, unlike the semiautomated variable method that underestimates end-diastolic and end-systolic volumes, provides more accurate estimates of biplane cineangiographic left ventricular volumes irrespective of the distance blood sample counts are acquired from the collimator.

An accurate noninvasive determination of left ventricular size and performance would be valuable for assessing disease progression and therapeutic interventions in cardiac patients. M-mode echocardiography, which depends on a single left ventricular minor-axis dimension measurement, may misrepresent left ventricular size and performance in patients with left ventricular dilation or segmental wall motion abnormalities (1–3). In patients with high quality two-dimensional echocardiographic left ventricular endocardial images, left ventricular volumes are systematically underestimated (4–6). Nevertheless, accurate two-dimensional echocardiographic estimates of left ventricular performance can be obtained from biapical images (6). The relative geometry-independent first transit and gated equilibrium radio-

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nuclide angiographic techniques are accurate noninvasive methods for determining left ventricular performance (6–10).

Recently, several methods have been described for estimating left ventricular volumes from radionuclide image and count data (11–20). The radionuclide count-based methods have provided a significant advance in the noninvasive estimation of left ventricular volumes because they are relatively geometry independent (17–20). However, these initial count-based radionuclide techniques have potential methodologic problems that might limit their accuracy for estimating individual absolute left ventricular volumes, including: 1) discordance in counting geometry during image and blood sample count acquisition (17); 2) inadequate attention to radioisotope decay (17); 3) variance in the duration of image acquisition (18); 4) lack of consideration of tissue photon attentuation (17,18,20); 5) complex methods of data acquisition or need for additional software development, or both (17,19); and 6) use of only single plane contrast cineangiography as the reference standard for direct comparison of absolute left ventricular volumes in patients with coronary artery disease and wall motion abnormalities (18,19). In addition, these studies have not systematically considered whether the methods of region of interest selection and blood sample count acquisition affect the accuracy of radionuclide left ventricular volume estimates, although different methods of obtaining each of these variables have been recommended (17–20).

Thus, to address these methodologic issues and simplify the methods of radionuclide data acquisition so that individual absolute left ventricular volumes may be determined accurately, the purposes of this investigation were: 1) to compare equilibrium radionuclide absolute left ventricular volume estimates calculated using a simple geometric attenuation correction with the corresponding left ventricular volumes obtained from biplane contrast cineangiograms; and 2) to assess the importance of left ventricular region of interest selection and blood sample count data on the accuracy of radionuclide absolute left ventricular volume estimates.

Methods

Patients

The study group consisted of 27 consecutive patients who signed a written informed consent form approved by our Institutional Review Board for biplane left ventricular cineangiography and coronary arteriography for routine diagnostic purposes followed within 24 hours by an equilibrium radionuclide angiographic study. There were no changes in clinical status or medical therapy during the 24 hours between the contrast cineangiographic and radionuclide angiographic studies. Also, the mean heart rate during the contrast cineangiogram of 79 ± 18 beats/min (± 1 standard deviation) did not differ significantly from that of 76 ± 21 beats/min during the radionuclide study.

There were 12 men and 15 women, whose ages ranged from 38 to 68 years (mean 50 years). The underlying cardiac disease was coronary artery disease in 12 patients, aortic stenosis in 1 patient, mitral regurgitation in 3 patients, aortic regurgitation in 2 patients, congestive cardiomyopathy in 4 patients, hypertrophic obstructive cardiomyopathy in 1 patient, tetralogy of Fallot in 1 patient and atypical chest pain with normal coronary arteries in 3 patients. Abnormal segmental wall motion was present in 8 of the 12 patients with coronary artery disease.

Cineangiography

Left heart catheterization was performed using the standard brachial or femoral technique. Simultaneous biplane left ventricular cineangiograms were obtained in the 30° right anterior oblique and 60° left anterior oblique/20° caudal tilt projections using biplane cineangiographic equipment (CGR Double Angiomax) after the injection of 40 to 60 cc radiopaque contrast material (Renografin-76) at 10 to 15 cc/s and 500 psi using a framing rate of 60/s, 9 inch (23 cm) image intensifier and 35 mm Varix cinefilm. In addition, the correction factors from each image intensifier to the left ventricular geometric center of mass were recorded for correction of magnification and pincushion distortion using precalibrated grids. The left ventricular end-diastolic images in both projections were outlined at the peak of the R wave determined from the simultaneously recorded electrocardiogram. The left ventricular end-systolic images in both projections were traced at maximal inward motion of the left ventricle. The left ventricular long axes were measured from the apex to the aortic valve plane. Image analysis was performed on one of the first three sinus beats after contrast injection when the effects of contrast material on myocardial performance are negligible (21). Left ventricular end-diastolic and end-systolic volumes were calculated using a modified biplane formula (22).

Equilibrium Radionuclide Angiography

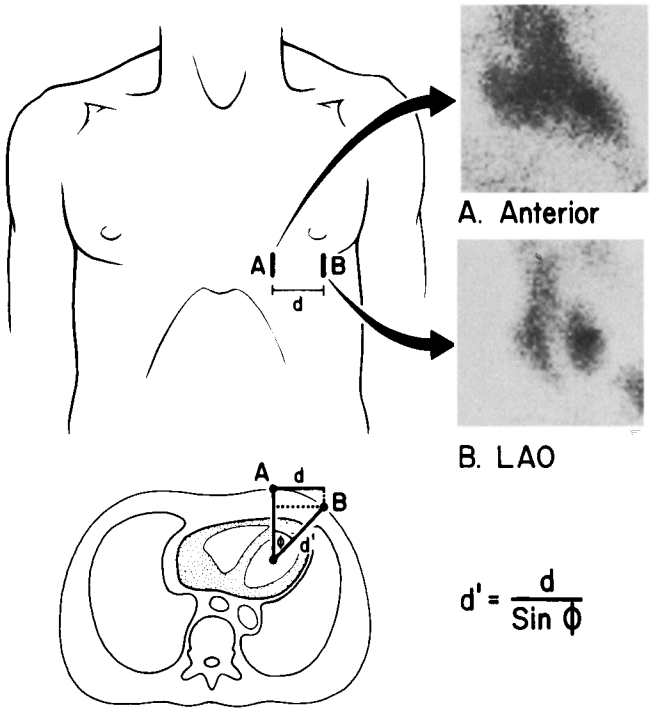
Gated equilibrium radionuclide angiographic images were obtained in the anterior and 45° left anterior oblique/10° caudal tilt projections after the intravenous administration of 20 mCi technetium-99m labeled human serum albumin. Images were acquired using a 37 photomultiplier tube standard field of view (25 cm) single crystal gamma scintillation camera equipped with a low energy all-purpose parallel hole collimator. R wave gated consecutive corresponding 30 ms frames were acquired in 64 × 64 byte mode matrix and stored in the computer remote memory (A_2, Medical Data System, Inc.) until the count information from 1,000 RR intervals had been processed. Midway through the oblique image acquisition, a 2 ml blood sample was obtained and the time recorded.

Geometric attenuation correction method. To obtain the distance from the gamma scintillation camera in the oblique position to the left ventricular geometric center of mass for blood sample counting and attenuation correction, a simple geometric method based on anatomic landmarks and experience from previous first-transit radionuclide studies was used (13). Briefly, with the camera in the oblique position, a point source containing technetium-99m labeled human serum albumin was placed over the left ventricle so that the source was equidistant from the anterior, inferoapical, septal and posterolateral margins of the left ventricle and a mark placed on the anterior chest wall (Fig. 1). The camera was repositioned in the anterior projection, and the point source was placed over the left ventricle midway between the pulmonary artery, which overlies the aortic valve plane (13) and the left ventricular apex and equidistant from the anterior and inferior left ventricular walls. Then, a second mark was placed on the anterior chest wall. The horizontal distance (d) between the two marks was measured in centimeters. This distance was the average of three measurements made independently by each of two observers. The distance (d′) from the camera in the oblique position to the geometric left ventricular center of mass was calculated using the following formula:

$$d' = \frac{d}{\sin 45°}, \qquad (1)$$

where d is the distance measured on the anterior chest wall and sin 45° = 0.707. Subsequently, the 2 ml blood sample was counted for 2 minutes on the collimator (d°) and at a distance (d′) from the collimator to obtain blood sample counts/2 min per 2 ml, and both times were recorded.

Figure 1. Method of obtaining the horizontal distance (d) for calculating the distance from the left ventricular center of mass to the camera in the 45° left anterior oblique projection for use in blood sample counting and attenuation correction. With the camera in the anterior (**A**) and oblique (**B**) projections, the technetium-99m point source was placed over the left ventricle and marks were placed on the anterior chest (**left**). The horizontal distance between the two marks was measured and the distance (d′) from the left ventricular center of mass to the camera in the oblique projection was calculated (**lower right**).



Left ventricular end-diastolic and end-systolic counts. *Semiautomated variable region of interest method.* Counts were obtained from the 45° oblique images using semiautomated variable and hand-drawn region of interest selection methods. To obtain left ventricular end-diastolic and end-systolic counts from the semiautomated variable region of interest method, the initial 30 ms frame was displayed. The operator positioned a box around the left ventricle, and the second derivative/threshold method was used to search for borders that optimally encompassed the left ventricle. The left ventricular borders were inspected visually by the operator during each frame of the cardiac cycle to ensure the integrity of the left ventricular outline. Background was obtained automatically from an end-systolic paraventricular region of interest placed inferior and lateral to the left ventricle. Subsequently, each image was smoothed and background subtracted, and a left ventricular time-activity curve was generated. From the left ventricular time-activity curve, the semiautomated variable end-diastolic and end-systolic counts were obtained.

Hand-drawn region of interest method. To obtain left ventricular end-diastolic and end-systolic counts from this method, the end-diastolic frame determined from the semiautomated variable left ventricular time-activity curve was displayed. Background was obtained manually from a left ventricular end-diastolic paraventricular region of interest placed inferior and lateral to the left ventricle. From the end-diastolic background-subtracted and smoothed image, the operator outlined manually a left ventricular end-diastolic region of interest that encompassed the left ventricle completely. In a similar manner, the end-systolic image was recalled. After smoothing and background subtraction, the operator outlined manually an end-systolic region of interest that totally encompassed the left ventricle but excluded adjacent structures, particularly the left atrium and descending aorta. From these left ventricular regions of interest, the hand-drawn end-diastolic and end-systolic counts were obtained. Finally, the two static blood sample images were displayed sequentially. The operator positioned a 10 × 15 pixel rectangular region of interest around each of the static blood sample images to obtain their respective blood sample counts.

Left ventricular end-diastolic and end-systolic volumes. These were calculated from the following equation:

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$$\frac{\text{Background-corrected left ventricular counts}}{\text{Blood sample counts}} \times A, \quad (2)$$

where background corrected left ventricular counts are end-diastolic or end-systolic left ventricular counts that have been normalized in the following manner:

$$\frac{\text{Background-corrected left ventricular counts}}{\text{1,000 beats}} \times \frac{\text{60s/min}}{\text{0.03 s/beat}}, \quad (3)$$

where 1,000 beats is the number of RR intervals processed, 0.03 s/beat is the frame rate during acquisition and 60 s/min converts from counts/s to counts/min. The blood sample counts in counts/2 min per 2 ml obtained either on the collimator (d°) or at a distance (d′) from the collimator were corrected for radioisotope decay by:

$$e^{\lambda t}, \quad (4)$$

where $\lambda = 0.693/T\text{-}1/2$, T-1/2 is 360 minutes for technetium-99m, and t is the time in minutes from drawing to counting the blood sample. Therefore, when normalized background-corrected left ventricular end-diastolic and end-systolic counts in counts/min are divided by decay-corrected blood sample counts/2 min per 2 ml, attenuated left ventricular end-diastolic and end-systolic volumes in milliliters are obtained. These values can be multiplied by A, which is equivalent to:

$$e^{\mu d'}, \quad (5)$$

where $\mu = 0.15\ cm^{-1}$, represents the linear attenuation coefficient for a 140 keV photon in water (19, 23), and d′ represents the distance in centimeters calculated to the geometric left ventricular center of mass from the gamma camera in the oblique position (equation 1) to correct for photon attenuation. This results in attenuation-corrected absolute left ventricular end-diastolic and end-systolic volumes in milliliters.

Data Analysis

The cineangiographic and radionuclide angiographic studies were processed by independent observers without knowledge of the results of the other study. To assess intra- and interobserver variability for determining left ventricular end-diastolic and end-systolic counts from the semiautomated variable and the hand-drawn region of interest methods, one observer processed 10 studies on two different occasions and a second observer independently processed the same studies. In addition, to determine count variability regions of interest were drawn around 10 blood samples on separate occasions by one of the investigators. To evaluate the interobserver variability in the calculation of d′, the average values of d′ determined by each of two observers for six studies were compared.

Comparisons of radionuclide angiographic and biplane cineangiographic left ventricular volumes were performed by least squares linear regression analysis to determine correlation coefficients, regression equations and 95% confidence intervals for the data and standard errors of the estimate. Group mean data are expressed as the mean ± 1 standard deviation and were compared by a paired *t* test. Multiple comparisons were made by an analysis of variance and Tukey's test where indicated. A significant difference was considered present when a probability (p) of 0.05 or less was observed.

Results

Semiautomated variable and hand-drawn region of interest count data. The average left ventricular end-diastolic counts from the semiautomated variable region of interest method of 18.2 ± 10.7 × 10^3 counts were less than the 21.8 ± 12.5 × 10^3 counts obtained using the hand-drawn region of interest technique ($p < 0.001$). The average left ventricular end-systolic counts of 11.9 ± 10.2 × 10^3 counts from the semiautomated variable region of interest method were also less than the 13.0 ± 11.0 × 10^3 counts obtained from the hand-drawn region of interest technique ($p < 0.01$).

Blood sample count data. The average blood sample counts obtained on the collimator (d°) of 3,450 ± 752 counts were greater than the 3,337 ± 769 counts obtained at a distance (d′) from the collimator ($p < 0.001$). Six patients had higher and 21 patients had lower blood sample counts at d′ compared with d°. In 6 of these 21 patients, blood sample counts were reduced 200 counts or more with a maximal reduction of 400 counts in 1 patient.

Distance measurements. The calculated distance d′ to the left ventricular geometric center of mass from the camera in the oblique position ranged from 6.7 to 12.2 cm with a mean of 8.9 ± 1.4 cm. Thus, the calculated attenuation correction factor, A, ranged from 2.8 to 6.2 with a mean value of 4.1 ± 1.0.

Semiautomated variable region of interest left ventricular volume data. Using the blood sample counts obtained on the collimator (d°), the radionuclide left ventricular end-diastolic volume estimates correlated with the corresponding cineangiographic end-diastolic volumes ($r = 0.95$, Fig. 2A). Using the blood sample counts obtained at a distance (d′) from the collimator, the radionuclide left ventricular end-diastolic volume estimates also correlated with the cineangiographic end-diastolic volumes ($r = 0.96$, Fig. 2B). However, both average radionuclide left ventricular end-diastolic volumes (179 ± 100 and 185 ± 102 ml, respectively) underestimated the mean cineangiographic end-diastolic volume of 217 ± 102 ml ($p < 0.001$). The two average radionuclide left ventricular end-diastolic volumes did not differ significantly (Fig. 3).

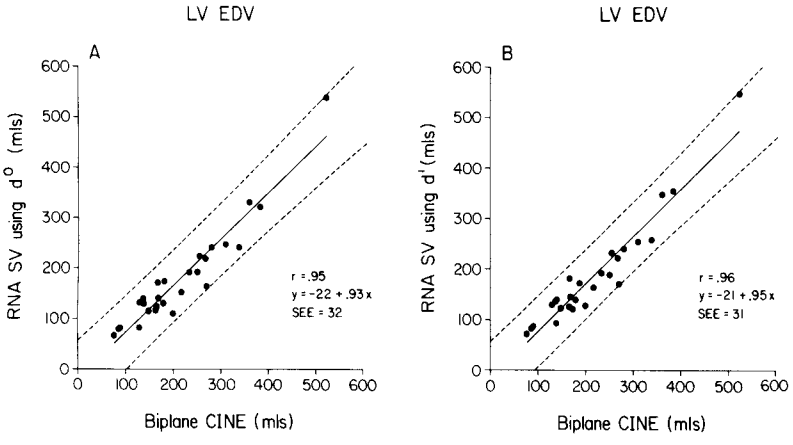
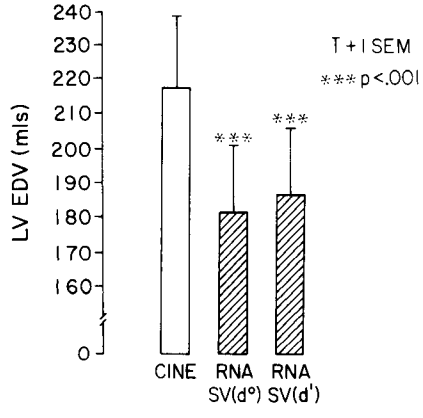


Figure 2. **A**, The left ventricular end-diastolic volume (LVEDV) estimates by radionuclide angiography (RNA SV) using the semiautomated variable region of interest selection method and the blood samples obtained on the collimator (d°) (**ordinate**) are compared with the corresponding volumes obtained by biplane cineangiography (**abscissa**). The individual points, regression line, 95% confidence intervals for the data, correlation coefficient (r), regression equation (y) and standard error of the estimate (SEE) are shown. **B**, The radionuclide left ventricular end-diastolic volume estimates using the semiautomated region of interest method and blood sample counts obtained at a distance (d′) from the collimator (**ordinate**) are compared with the corresponding cineangiographic left ventricular end-diastolic volumes (**abscissa**) in a format similar to **A**.

Using the blood sample counts obtained on the collimator (d°), the radionuclide left ventricular end-systolic volume estimates correlated with the corresponding cineangiographic end-systolic volumes (r = 0.96, Fig. 4A). Using the blood sample counts obtained at a distance (d′) from the collimator, the radionuclide left ventricular end-systolic volume estimates also correlated with the cineangiographic end-systolic volumes (r = 0.97, Fig. 4B). Using blood sample counts at d°, the average radionuclide left ventricular end-systolic volume (116 ± 98 ml, $p < 0.05$) was less than the mean cineangiographic end-systolic volume of 128 ± 98 ml, and while using blood sample counts at d′, the average radionuclide left ventricular end-systolic volume (122 ± 104 ml) did not differ significantly from the mean cineangiographic end-systolic volume. The average radionuclide left ventricular end-systolic volumes also did not differ significantly (Fig. 5).

Figure 3. The average left ventricular end-diastolic volumes (LVEDV) (**ordinate**) by cineangiography (CINE) and radionuclide angiography (RNA) using the semiautomated variable region of interest selection method and blood sample counts (SV) obtained on (d°) and at a distance (d′) from the collimator are compared. The **bars** represent the mean ± 1 standard error of the mean. Significant differences between the radionuclide angiographic and cineangiographic values are noted.



Hand-drawn region of interest left ventricular volume data. Using the blood sample counts obtained on the collimator (d°), the radionuclide left ventricular end-diastolic volume estimates correlated with the corresponding cineangiographic end-diastolic volumes (r = 0.96, Fig. 6A). Using the blood counts obtained at a distance (d′) from the collimator, the radionuclide left ventricular end-diastolic volume estimates continued to correlate with the cineangiographic end-diastolic volumes (r = 0.96, Fig. 6B). In addition, both average radionuclide left ventricular end-diastolic volumes (212 ± 104 and 220 ± 106 ml, respectively) did not differ significantly from the mean cineangiographic end-diastolic volume of 217 ± 102 ml. Furthermore, the average radionuclide left ventricular end-diastolic volumes did not differ significantly (Fig. 7).

Using the blood sample counts obtained on the collimator (d°), the radionuclide left ventricular end-systolic volume estimates correlated with the corresponding cineangiographic end-systolic volumes (r = 0.98, Fig. 8A). Using the blood sample counts obtained at a distance (d′) from the collimator, the radionuclide left ventricular end-systolic volume estimates also correlated with the cineangiographic end-systolic volumes (r = 0.97, Fig. 8B). In addition, both average radionuclide left ventricular end-systolic volumes (132 ± 112 and 136 ± 115 ml, respectively) did not differ significantly from the mean cineangiographic end-systolic volume of 128 ± 98 ml. Also, the mean radionuclide left ventricular end-systolic volumes did not differ significantly (Fig. 9).

Left ventricular ejection fraction data. The left ventricular ejection fraction estimates using the semiautomated variable and hand-drawn region of interest selection methods correlated with the cineangiographic ejection fractions (r = 0.85 and 0.88, respectively). However, the mean

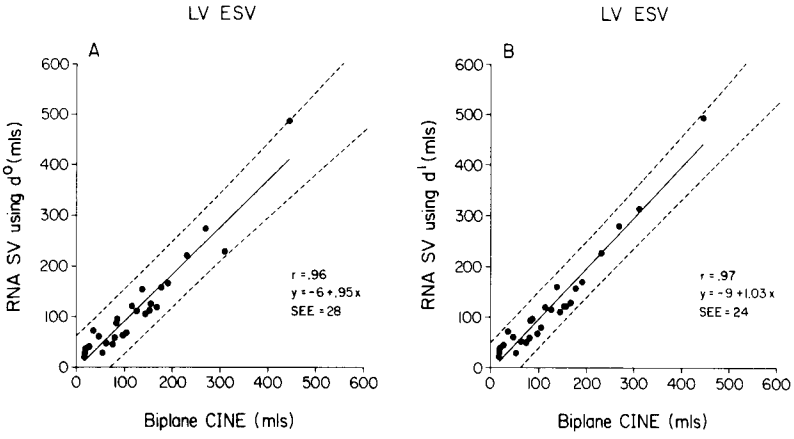
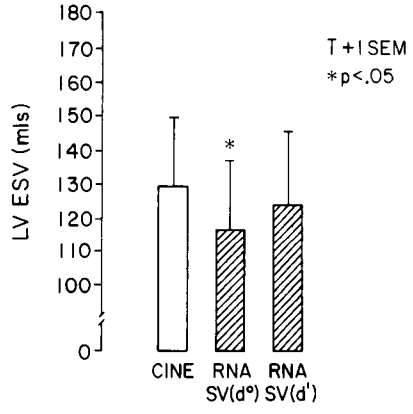


Figure 4. A, The radionuclide left ventricular end-systolic volume estimates using the semiautomated variable region of interest method and blood sample counts obtained on the collimator (d°) (**ordinate**) are compared with the corresponding cineangiographic (CINE) end-systolic volumes (ESV) (**abscissa**) in a format similar to Figure 2. **B,** The radionuclide left ventricular end-systolic volume estimates using the semiautomated variable region of interest method and blood sample counts obtained at a distance (d′) from the collimator, on the **ordinate**, are compared with the corresponding cineangiographic end-systolic volumes on the **abscissa** in a similar format.

radionuclide semiautomated variable left ventricular ejection fraction of 41 ± 18% underestimated the average cineangiographic ejection fraction of 48 ± 20% ($p < 0.001$), and the mean radionuclide hand-drawn left ventricular ejection fraction of 45 ± 20% did not differ from the average cineangiographic ejection fraction.

Reproducibility. The accuracy of radionuclide left ventricular volumes is dependent on the reproducibility of the variables: left ventricular end-diastolic and end-systolic counts, blood sample counts and d′. The intraobserver and interobserver reproducibility for both the left ventricular end-diastolic and end-systolic counts using the semiautomated variable region of interest method was r = 0.99 and 0.98, respectively. Similarly, the intraobserver and interobserver reproducibility for both the left ventricular end-diastolic and end-systolic counts using the hand-drawn region of interest method was r = 0.98 and 0.97, respectively. The reproducibility of blood sample counts was r = 0.99. Thus, intra- and interobserver reproducibility of the radionuclide left ventricular end-diastolic and end-systolic volumes was r = 0.98 and 0.97, respectively, for the semiautomated variable and r = 0.97 and 0.95, respectively, for the hand-drawn region of interest selection method.

Figure 5. The average left ventricular end-systolic volumes (LV ESV) by cineangiography and radionuclide angiography using the semiautomated region of interest selection method are shown in a format similar to Figure 3.



Discussion

Previous Radionuclide Left Ventricular Volume Studies

Several studies have attempted to estimate left ventricular volumes using first transit or gated equilibrium radionuclide angiographic image, or both, or count data (11–20). However, the development of geometry-independent equilibrium radionuclide angiographic count-based methods provided an important advance in the noninvasive estimation of left ventricular volumes (17–20). Initially, Slutsky et al. (17) evaluated four different methods and reported that the most accurate technique was one which normalized left ventricular counts obtained using a semiautomated variable region of interest selection method for heart rate, frame rate and plasma blood sample counts. When radionuclide left ventricular end-diastolic and end-systolic volume indexes using this technique were compared with biplane cineangiographic left ventricular volumes in 17 patients, correlations were observed (r = 0.97 and 0.98, respectively). Subsequently, Dehmer et al. (18) evaluated 22 patients with equilibrium radionuclide angiography to further prove the ability of radionuclide count-based methods to estimate left ventricular volumes. They observed a good correlation between left ventricular end-diastolic and end-systolic volume indexes calculated from radionuclide angiographic hand-drawn region of interest count data and single plane cineangiograms (r = 0.99 for both).

Limitations of both previous methods. These early equilibrium radionuclide volume studies have potential methodologic problems that might limit their ability to estimate absolute left ventricular volumes in an individual patient. First, left ventricular count and plasma blood sample count data were acquired under different geometric conditions (17). Second, plasma blood samples were counted 48 hours after acquisition and inadequate attention was given

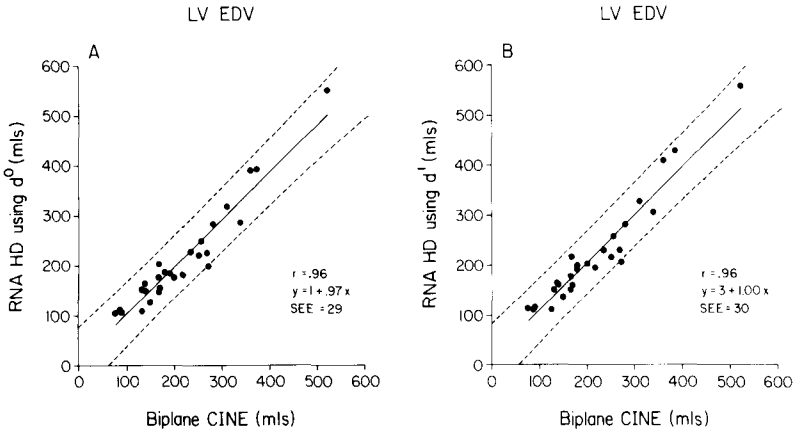
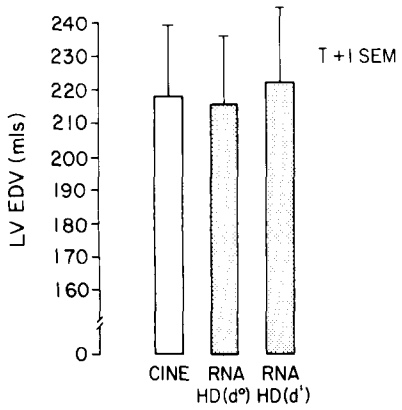


Figure 6. **A**, The radionuclide left ventricular end-diastolic volume estimates using the hand-drawn (HD) region of interest selection method and blood sample counts obtained on the collimator (d°), on the **ordinate**, are compared with the corresponding cineangiographic end-diastolic volumes on the **abscissa** in a format similar to Figure 4. **B**, The radionuclide left ventricular end-diastolic volume estimates using the hand-drawn region of interest method and blood sample counts obtained at a distance (d') from the collimator, on the **ordinate**, are compared with the corresponding cineangiographic end-diastolic volumes on the **abscissa** in a similar format.

to radioisotope decay (17). Third, an image acquisition time correction was used that may have introduced some variability in each study (18). Fourth, 30° right anterior oblique single plane cineangiograms were used initially as the reference standard for direct comparison with the radionuclide left ventricular volume estimates (18). Because several patients had coronary artery disease and abnormal wall motion, a 30° right anterior oblique single plane cineangiogram may have inaccurately estimated left ventricular volumes in some of these patients (24–26). However, Dehmer et al. (27) further substantiated their method of obtaining noninvasive left ventricular volume indexes by reporting a correlation (r = 0.95) between stroke volume estimates from their modified radionuclide method and those obtained by thermodilution measurements. Finally, both of these radionuclide volume studies depend heavily on regression equation correction of radionuclide left ventricular volume indexes to obtain absolute left ventricular volumes (17,18). These measurements may not be accurate in an individual patient, because radionuclide absolute left ventricular volume estimates may depend most on the amount of photon attenuation in each patient, which these studies ignored (17,18). Nevertheless, an equilibrium radionuclide count-based method has been shown to be better than geometric methods of estimating left ventricular volumes from either first-transit or equilibrium radionuclide angiographic images (20).

Figure 7. The average left ventricular end-diastolic volumes by cineangiography and radionuclide angiography using the hand-drawn region of interest selection method are shown in a format similar to Figure 5.



Recently, Links et al. (19) studied 35 patients to assess the accuracy of an attenuation-corrected radionuclide angiographic count-based method for estimating absolute left ventricular volumes. The radionuclide left ventricular end-diastolic volume estimates calculated using the count data obtained from a semiautomated variable region of interest selection method correlated with the corresponding single plane 30° right anterior oblique cineangiographic end-diastolic volumes (r = 0.95), but they underestimated cineangiographic volumes substantially. The radionuclide left ventricular end-systolic volume estimates calculated from the radionuclide left ventricular end-diastolic volumes and ejection fraction measurements also correlated with the cineangiographic end-systolic volumes (r = 0.95). Moreover, radionuclide end-systolic volumes obtained using a hand-drawn region of interest selection method correlated with the corresponding cineangiographic end-systolic volumes (r = 0.95). However, there are some potential methodologic problems that might limit the wide applicability of this technique. First, blood samples were counted on the collimator in 19 patients and at 5 cm or more from the collimator in the remaining 16 patients. As a result, some error in absolute left ventricular volume determinations may have been introduced. Although the authors discussed the theoretical advantages of counting blood samples at a distance from the collimator, no data were presented to support this contention. Second, the distance from the gamma camera to the left ventricular center of mass was calculated using a point source placed on the chest in the left anterior oblique projection and a computer-derived peak count rate profile in the anterior projection from a specially derived software program that is not widely available. Finally, single plane 30° right anterior oblique cineventriculograms were the reference standard for left ventricular volumes although 20 of

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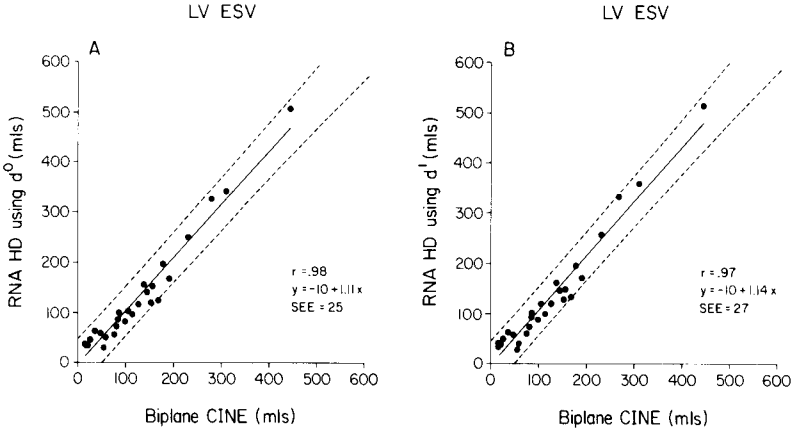


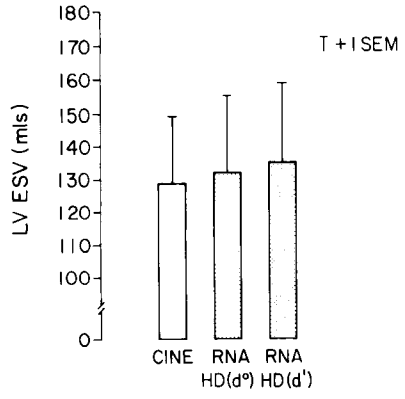
Figure 8. A, The radionuclide left ventricular end-systolic volume estimates using the hand-drawn region of interest method and blood sample counts obtained on the collimator (d°), on the **ordinate**, are compared with the corresponding cineangiographic end-systolic volumes on the **abscissa** in a format similar to Figure 6. **B**, The radionuclide left ventricular end-systolic volume measures using the hand-drawn region of interest method and blood sample counts obtained at a distance (d′) from the collimator, on the **ordinate**, are compared with the corresponding cine angiographic end-systolic volumes on the **abscissa** in a similar format.

the 26 patients with coronary artery disease in the study had abnormal left ventricular wall motion (24–26). Nevertheless, this study indicated that attenuation correction of radionuclide count data may provide accurate estimates of absolute left ventricular volumes without a strong dependence on regression equation correction of radionuclide left ventricular volume indexes.

Present Investigation of Radionuclide Left Ventricular Volumes

The present investigation was designed to eliminate these potential methodologic problems, simplify the radionuclide data collection and processing for attenuation correction and validate the accuracy of this noninvasive radionuclide method of calculating absolute left ventricular volumes. The radionuclide images were acquired for 1,000 cardiac cycles to avoid variability in the duration of radionuclide image acquisition. All left ventricular count data were obtained using semiautomated variable and hand-drawn regions of interest to determine their relative importance for estimating absolute left ventricular volumes. In addition, the blood samples were counted on (d°) and at a distance (d′) from the collimator for each patient to evaluate the practical effects of blood sample count data on radionuclide absolute left ventricular volume estimates. Furthermore, the blood sample counts were all decay corrected. Finally, a simple geometric method was used to obtain the distance from the gamma scintillation camera in the left anterior oblique position to the left ventricular center of mass for attenuation correction.

Figure 9. The average left ventricular end-systolic volumes by cineangiography and radionuclide angiography using the hand-drawn region of interest selection method are shown in a format similar to Figure 7.



Our data indicate that a simple geometric method of attenuation correction of radionuclide count data can provide accurate estimates of absolute left ventricular volumes without a strong dependence on regression equation correction of left ventricular volume indexes. The semiautomated variable region of interest method significantly underestimates biplane cineangiographic left ventricular end-diastolic and end-systolic volumes. These data are consistent with those of Links et al. (19). In contrast, we observed that the hand-drawn region of interest selection method accurately estimates both biplane cineangiographic left ventricular end-diastolic and end-systolic volumes. This was due to a greater number of background-corrected counts in the hand-drawn regions compared with the semiautomated regions. In addition, counting blood samples on (d°) or at a distance (d′) from the collimator was not of practical importance for calculating radionuclide absolute left ventricular volumes, because there was no significant difference in the average radionuclide left ventricular end-diastolic and end-systolic volumes using blood sample counts acquired by either method. Therefore, our results indicate that a simple geometric attenuation correction of equilibrium radionuclide angiographic count data can provide accurate estimates of biplane cineangiographic left ventricular volumes when the hand-drawn end-diastolic and end-systolic regions of interest and blood sample counts obtained on or at a distance from the collimator are used.

Limitations of present method. There are certain potential limitations to the present investigation that must be considered. First, left ventricular end-diastolic and end-systolic background-corrected count data may have varied and

affected the volume calculations. However, the semiautomated variable and hand-drawn region of interest left ventricular end-diastolic and end-systolic count data were highly reproducible. Second, the blood sample counts may have varied and affected the volume calculations. However, the blood sample count data were also highly reproducible and an insignificant difference between counts was observed when the blood samples were counted on separate occasions. Third, the distance d′ used for attenuation correction could have affected the left ventricular volume calculations. This distance was determined independently by at least two observers at the time of data acquisition. This geometric calculation of d′ uses anatomic landmarks that can be identified easily making this a simple method of obtaining the distance measurement necessary for attenuation correction. Nevertheless, an under- or overestimation of d′ could have introduced significant variability in the attenuation-corrected radionuclide absolute left ventricular volumes. However, the individual variability in the calculated values of d′ was low. Also, the radionuclide left ventricular volume estimates were reproducible, and they correlated with the corresponding cineangiographic left ventricular volumes. Moreover, the standard errors of the estimate, particularly for the hand-drawn region of interest selection method, were narrow, suggesting that this method can provide accurate estimates of left ventricular end-diastolic and end-systolic volumes in individual patients irrespective of left ventricular size. Finally, the assumption that μ is 0.15 cm^{-1} consistently from the left ventricular center of mass to the gamma scintillation camera is only an approximation. Because several tissues intervene with different linear attenuation coefficients, one might expect some variability in radionuclide left ventricular volumes. However, the close correlations and accurate radionuclide left ventricular volume estimates observed would suggest that this is an acceptable assumption.

Conclusions

Attenuation correction of radionuclide left ventricular count data using a simple geometric approach provides accurate estimates of the corresponding biplane cineangiographic left ventricular volumes. In addition, the hand-drawn region of interest technique is more accurate than the semiautomated variable region of interest selection method for estimating individual left ventricular end-diastolic and end-systolic volumes. Finally, the distance from the collimator at which blood samples are counted does not make a significant difference in the accuracy of calculated radionuclide absolute left ventricular volumes. Therefore, this simple geometric method of attenuation correction to obtain absolute left ventricular volumes from equilibrium radionuclide angiographic count data may be widely applicable for accurately assessing disease progression and therapeutic interventions in individual patients with cardiac disease.

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