Reply

Dr. Buell and colleagues have suggested that they can calculate true left ventricular (LV) end-diastolic volumes by using an average attenuation correction determined from absorptions of the LV blood, anterior wall, and thoracic wall obtained from 40 patients, using transmission CT data for ascertaining thoracic wall thickness. A sophisticated parabolic background correction was used. They state that this technique provided a high correlation for LV end-diastolic volumes. Problems occurred with the assumption of an average thickness in obese patients, and, thus, an individual attenuation-correction factor might be preferable in these selected cases.

Although good correlation coefficients have been reported for both attenuation-corrected and uncorrected radionuclide LV volume estimates (*1-3*), this does not necessarily imply that the application of an average attenuation-correction factor, a regression equation, will provide accurate absolute volume estimates. Our recent article in the *Journal* addressed the issue of whether individual attenuation correction of uncorrected radionuclide LV volume indices was necessary to obtain accurate estimates of absolute ventricular volumes both at end diastole and end systole. Our data would suggest that to obtain accurate absolute LV volumes by equilibrium radionuclide angiography, individual attenuation-correction factors must be calculated for each patient (*3*).

We appreciate the comments of Dr. Buell and his colleagues, for they stimulate a discussion of these radionuclide techniques for estimating absolute LF volumes.

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Re: Estimates of Left-Ventricular Volumes by Equilibrium Radionuclide Angiography: Importance of Attenuation Correction

We have read with interest the recent article by Starling et al. (*1*). They have used the volume technique first proposed by Links et al. (*2*), which requires a depth measurement, to answer the question, "to correct, or not to correct for attenuation?"

They have confirmed—as we and others had already demonstrated—that attenuation correction leads to better estimates of true left-ventricular (LV) volumes when using count-based radionuclide angiography (RA) (Table 1).

The authors are incorrect when they say "early RA methods of estimating LV volumes did not apply an attenuation correction." Slutsky et al. (*6*) and Dehmer et al. (*3*) used a regression line, the slope of which we have previously shown (*4*) is the average transmission factor (attenuation correction), given by $e^{-\mu d}$, where μ = the linear attenuation coefficient for Tc-99m in the body, and d = the depth from the LV center to the chest wall.

Since quantitative nuclear medicine procedures have always found it necessary to perform attenuation correction for organs other than the heart (*7,8*), the issue is not whether or not attenuation correction should be performed, but which method is best.

If we examine the equation necessary for LV volume determination:

$$\text{LV volume} = \frac{\text{net LV count rate}}{\text{blood-sample count rate} \times e^{-\mu d}},$$

there are only three variables needed to solve for LV volume (Table 2). There are obvious advantages to using semiautomated, as opposed to manual, regions of interest for determining the net LV count rate. The blood-sample count rate should be obtained in a geometry similar to that of the left ventricle, using a container that minimizes self-attenuation. Recently, numerous methods have been proposed to correct for attenuation ($e^{-\mu d}$) (*2,4,5*).

From available data we have summarized the results of several methods that have been used to determine LV volumes (Table 1)—along with regression equations, correlation coefficients (r), standard errors of the estimate (s.e.e.), transmission factors, 95% prediction intervals, and their respective percentage errors—for both end-diastolic and end-systolic volumes. The 95% prediction intervals give the predicted range of radionuclide volumes for a given angiographic volume. It is not surprising that the regression method of Dehmer et al. yields the poorest results, since it is theoretically unreasonable to assume the same transmission factor (the slope of the regression line) for each patient. In analyzing the data presented by Dehmer et al., we found that if one patient (#15) was dropped from their analysis (*3*), the transmission factor would change from 0.17 to 0.20. A second paper by Dehmer et al. (*13*) uses the latter transmission factor, and the correlation coefficients for comparing RA LV volumes with contrast ventriculography, decrease to 0.86 and 0.73 for end-diastole and end-systole, respectively.

The method of Links et al. (*2*) yields SEEs and 95% prediction intervals that are large, especially for end-systolic volumes. The Links et al. technique assumes that $\mu = 0.15\ cm^{-1}$. This is true only with narrow-beam geometry. Since scatter is inherent in clinical nuclear medicine imaging with window settings of 15-25%, the assumption of a narrow-beam μ for attenuation correction is incorrect. The narrow-beam μ of $0.15\ cm^{-1}$ can only be used with a buildup factor that corrects for the scatter contribution (*14*).

The method of Starling et al. (*1*), which is a modification of the Links (*2*) technique, still shows relatively large errors at small volumes. Others have used ultrasound to measure more accurately the depth to the center of the left ventricle (*12*), but no refinement in the depth measurement will compensate for an incorrect value of μ.

An esophageal point source behind the left ventricle (*4*) gives results similar to those of Starling et al. for end-diastole, but there is marked improvement particularly for end-systolic volumes up to 100 ml. A buildup-factor technique that we have recently proposed results in an improvement in the calculation of the LV volumes (*5*).

In conclusion, we believe that count-based methods for determining LV volumes, especially at end-systole, will become increasingly important for the application of end-systole pressure-volume methods for characterizing LV contractility (*15-17*). Count-based methods will be particularly important for patients with regional abnormalities of wall motion, especially at end-systole. Semiautomated regions of interest will be needed particularly in performing serial studies, and standardized methods for counting the blood sample need to be established. Finally, as in all other nuclear medicine procedures, proper attention to attenuation correction is required.