Validation of Left Ventricular Volume Measurements by Radionuclide Angiography

Mario S. Verani, Jesus Gaeta, Adrian D. LeBlanc, Lawrence R. Poliner, LeAnna Phillips, Jeffrey L. Lacy, John I. Thornby, and Robert Roberts

Sections of Cardiology and Nuclear Medicine, Department of Internal Medicine, Baylor College of Medicine, Houston, Texas

A nongeometric, attenuation-corrected technique to quantitate left ventricular volumes using equilibrium radionuclide angiography was validated in vitro and in vivo. In vitro experiments were performed to derive a linear attenuation coefficient, which was then employed in the volume determinations using balloons in a water bath. Good in vitro correlation was found between radionuclide and actual volumes ($r = 0.99$, $p < 0.0001$), over a wide range (5 to 400 ml). In vivo validation was done by comparing the nuclear technique to contrast angiography in 29 patients: Good correlations were found for end-diastolic volume ($r = 0.98$), end-systolic volume ($r = 0.95$), stroke volume ($r = 0.96$), and ejection fraction ($r = 0.85$). When the conventional linear attenuation coefficient was used, the radionuclide technique consistently overestimated volumes in vitro and in vivo. Although high intraobserver and interobserver correlation coefficients were found (r from 0.88 to 0.93), significant individual variability existed, particularly in the interobserver data. Our data provide unique validation of radionuclide volume determinations, using an experimentally determined attenuation coefficient, which results in improved accuracy.

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Determination of left ventricular volumes at rest and during interventions, such as exercise, may yield important physiologic information when assessing patients with coronary artery disease or valvular dysfunction. Left ventricular volumes have been measured employing several radionuclide techniques (*1–12*) most of which require geometric assumptions (*1–5,8,11*) or the use of a regression equation to correct for the obtained values (*6,7,11*). Absorption and scatter of the gamma rays are major limiting factors when attempting to measure cardiac volumes by radionuclide angiography since they drastically attenuate the detectable radiation emanating from the patient. Links et al. (*9*) have described a technique to measure true left ventricular volumes attempting to correct for this radiation attenuation. This technique uses an attenuation correction algorithm, employing a conventional attenuation coefficient, derived from narrow beam geometry. In this investigation, we performed in vitro experiments in various phantom models, to determine an attenuation coefficient more applicable to cardiac imaging, namely, a broad-beam geometric model. This coefficient was then used for the in vivo volume determinations. In vivo comparisons were performed between contrast and radionuclide angiography in 29 patients and factors which may potentially limit its application were assessed.

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For reprints contact: Mario S. Verani, MD, Associate Professor of Medicine, Baylor College of Medicine, The Methodist Hospital, 6565 Fannin F-905, Houston, TX 77030.

MATERIAL AND METHODS

All studies were done using a single-crystal gamma camera with a 1/2-in. sodium iodide crystal, and a low-energy, parallel-hole, all-purpose collimator. Images and data processing were done in dedicated microcomputers attached to the cameras*. The camera's energy discriminator was set at 140 keV with a 20% window. In the phantom experiments, images were acquired to a minimum of 200 counts/pixel over the region of interest (ROI). In the human studies, imaging was performed for a fixed time of 4 min.

PHANTOM STUDIES

Two phases of phantom studies were evaluated. In the first phase, the attenuating effect of scatter thickness on radioactivity counts was studied by imaging 10- and 50-ml syringes filled with technetium-99m (^{99m}Tc) pertech-

netate in ten different water depths, ranging from 3.2 to 21.4 cm from the camera head. The counts in the ROI encompassing the entire syringes were determined in the computer. The mathematical relationship between counts and distances was plotted; the slope of this relation was the experimental attenuation coefficient and it was used in all subsequent volume determinations.

In the second phase, a thin-walled rubber balloon was imaged at a fixed distance centered 7.5 cm from the camera head inside a thin-walled lucite container filled with water to provide an attenuation and scattering medium. The balloon was filled with known volumes of water and ^{99m}Tc ranging from 5 to 400 ml in 25-ml increments. Imaging was performed in these experiments until 200 counts/pixel were accumulated over the center of the balloon. An ROI encompassing the whole balloon was drawn manually with a lightpen and the counts in the ROI determined by the computer. A 25-ml sample of the same ^{99m}Tc solution was also counted at a distance of 7.5 cm from the camera, in order to provide a calibration factor to convert counts into volumes in the balloon experiments.

IN VIVO STUDIES

In the human phase of the investigation, 29 patients, ages 32 to 70, mean 56 yr, scheduled to undergo diagnostic cardiac catheterization were studied by radionuclide angiography either the day before or after the catheterization. All patients were clinically stable. Medications used at the time of the radionuclide angiography were continued up to the time of cardiac catheterization. Diagnoses were variable; most patients had coronary artery disease (n = 19), but others were normal (n = 6), had valvular heart disease (n = 2), or cardiomyopathy (n = 2). Left ventricular contrast cineangiograms in the 30° right anterior oblique projection were performed with the left ventricular injection of 35 to 50 ml of Hypaque-76 or Renografin-76 and filmed at 30–45 frames/sec. All left ventricular angiograms were performed in a pain-free state, prior to coronary angiography or administration of sublingual nitroglycerin. Angiograms with extrasystoles were not used. The end-diastolic frame was chosen as the largest image and the end-systolic the smallest in the cardiac cycle. The first or second well-opacified beat was always used. Contrast left ventricular volumes were calculated by the area-length method using Kennedy's regression equation (*13*).

RADIONUCLIDE LEFT VENTRICULAR VOLUMES STUDIES

Radionuclide angiograms were performed using an in vivo red cell labeling technique (*14*). An equilibrium, multigated acquisition was initiated 10 min after the administration of 25–30 mCi of ^{99m}Tc. The same scintillation camera and collimator were used for the phantom studies and human studies. Special software was developed and written in our laboratory to acquire, record, and process the images. Imaging was performed in the left anterior oblique projection which best visualized the interventricular septum (usually 30 to 40°). The exact angle of the camera was entered into the computer. Caudal angulation was not used. Studies were acquired on a 64 × 64 matrix, with 32 frames/cardiac cycle, for a preset time of 240 sec. Immediately upon completion of imaging, without moving the camera or the patient, a small cobalt-57 spherical source was positioned and taped to the patients left lateral chest wall, to overlap with the center of left ventricle, as observed in the persistent oscilloscope. The camera was then rotated to the anterior projection and a static full-field image of the heart and left ventricular marker was acquired for 60 sec. A peripheral blood sample (5 ml) was drawn in a vein contralateral to the injection site, and counted directly on the inverted camera detector head for 60 sec. The time from the beginning of the left ventricular imaging to the blood counting was entered into the computer, for appropriate decay correction. Image processing proceeds using manual border recognition of the individual frames, after a nine-point smoothing and manually determined background selection, as previously described (*15-18*). The counts of the left ventricular ROI were 33,716 ± 9,605 in end-diastole and 28,954 ± 9,119 in end-systole, prior to background subtraction. Left ventricular volumes were calculated using the formula (*9*):

$$\text{LV volume} = \frac{\text{LV count rate}/e^{-\mu d}}{\text{Blood counts rate/ml}}$$

where μ = attenuation coefficient, and d = distance from left ventricle center to camera.

$$\text{LV count rate} = \frac{\text{Counts in LV frame}}{\text{Time/frame} \times \text{no. cycles acquired.}}$$

Using the static image, the observer identifies with the joystick, the center of the marker, and the center of the left ventricle. Using the distance between these two points, and the camera's angle, the distance from the left ventricular center to the camera is computer-calculated by a simple trigonometric relation (*9,12*). The final output consists of the absolute end-diastolic volume, end-systolic volume, heart rate, stroke volume, cardiac output, and ejection fraction.

FACTORS AFFECTING RADIONUCLIDE LEFT VENTRICULAR VOLUMES

Intraobserver variability

In order to assess the intraobserver variability of the volume determinations, 19 studies were completely reprocessed by the same observer, blind as to the first

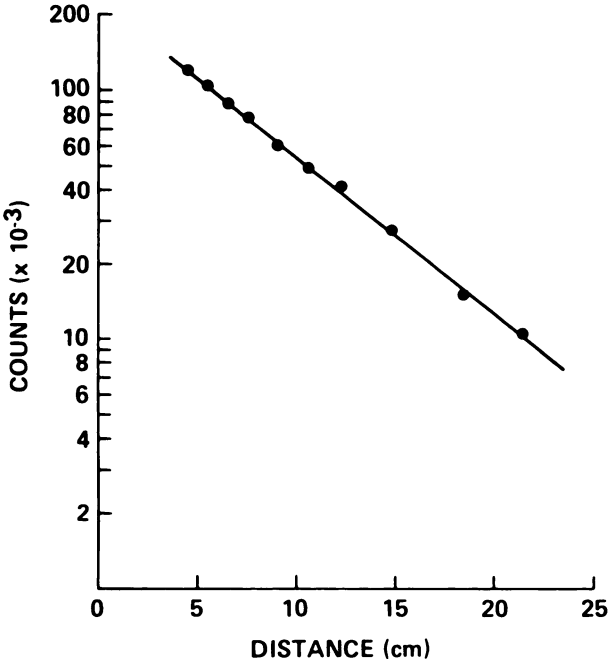

FIGURE 1
Effect of attenuation distance on attenuation. Logarithmic relation was found, with attenuation coefficient of 0.144 cm^{-1}. $Y = (1{,}000) \times 230.09e^{-0.1448\ DIST}$; $r = 0.97$; $p < 0.0001$

results, 2 mo after the first determination. In addition to the left ventricular volumes, the intraobserver reproducibilities of the background and left ventricular depth were analyzed. To assess the reproducibility of the manually drawn left ventricular ROI, this process alone was done in duplicate in 29 patients in whom the background and the left ventricular depth were kept constant.

In 15 patients, one observer processed the volume data using three different backgrounds: a "good" background, determined in the end-systolic frame, 2 pixels behind the left ventricular posterolateral wall, anterior to the descending aorta; a "high" one, deliberately chosen to represent an area where the background was higher than the "optimal" one; and a "low" one, thought to represent an area around the left ventricle with counts below the areas considered "optimal" (usually over the gastric bubble).

Interobserver variability

In 21 patients processing was performed independently by a second observer on a different day. The reproducibility of the left ventricular depth was measured, in addition to the volumes reproducibility.

Statistical analysis

Regression analysis, correlation coefficients (r), standard error of the estimate (s.e.e), 95% confidence intervals and regression equations were determined using standard statistical techniques. The significance of the correlation was assessed using the F-ratio test. Differences between paired variables were assessed by paired t-tests. Significance was assessed at the $p < 0.05$ level. Data are expressed as the mean ± standard deviation (s.d.).

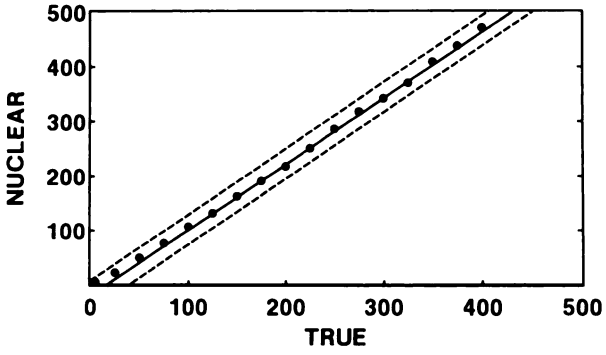

FIGURE 2
In vitro correlation between measured (nuclear) and true volumes. $VOL_N = -11.71 + 1.19 \times VOL_T$; $r = 0.99$, $p < 0.0001$; s.e.e. = 5.2 ml

RESULTS

Phantom studies

The effect of variable attenuation distances upon the measured count rate is shown in Fig. 1, for the 50-ml syringes. The correlation was high ($r = 0.97$) over a wide range of distances, from 4.5 to 21 cm. The distance compared with count rate followed a logarithmic relationship with an attenuation coefficient of 0.144 cm^{-1} (Fig. 1). When a 10-ml volume source was used, the correlation was also excellent ($r = 1.0$), with a similar attenuation coefficient.

The correlation between the measured volumes (balloon in water bath) and true volumes is shown in Fig. 2. There was a high correlation, with a correlation coefficient of $r = 0.99$. The radionuclide volumes (226 ± 149 ml) were, however, higher than true balloon volumes (200 ± 125), particularly for larger volumes.

IN VIVO STUDIES

Radionuclide compared with contrast volume determinations

The radionuclide and contrast volumetric data are shown in Table 1. The correlation ($r = 0.98$), for a wide range of end-diastolic volumes was high (Fig. 3). A good correlation ($r = 0.94$) was also found for the end-systolic volumes (Fig. 4). A close correlation ($r = 0.96$) was obtained for the stroke-volume (Fig. 5) with the two techniques. The ejection fraction (Fig. 6) was similar with the nuclear compared with contrast techniques (58 ± 13% compared with 58 ± 12%, pns) with a good correlation coefficient ($r = 0.85$).

If the conventional attenuation coefficient of 0.15 cm^{-1} were used in the calculations, instead of our experimen-

TABLE 1
Volumetric Data* by Radionuclide and Contrast Angiography

Patient no.	EDV†N‡	EDVC§	ESV¶N	ESVC	SVN**	SVC	LEFN††	LEFC
1	142	153	46	54	96	99	67	65
2	156	136	77	59	79	77	50	57
3	100	96	35	41	65	55	65	57
4	263	258	105	82	158	176	60	68
5	105	95	39	41	66	54	63	57
6	279	291	114	145	165	146	59	50
7	307	281	200	159	107	122	35	43
8	120	146	34	48	86	98	71	67
9	101	113	42	42	59	71	58	63
10	84	103	34	39	50	64	59	62
11	121	135	47	53	74	82	61	61
12	107	108	64	55	43	53	40	49
13	110	106	26	34	84	72	76	68
14	161	190	37	64	124	126	77	66
15	92	112	25	29	67	83	73	74
16	144	155	53	56	91	99	63	64
17	400	355	140	163	260	192	65	54
18	175	149	73	65	102	84	58	56
19	164	171	50	47	114	124	69	72
20	570	346	198	153	372	193	65	56
21	317	319	165	168	152	151	48	47
22	58	65	29	28	29	37	50	57
23	125	137	78	82	47	55	37	40
24	80	88	41	28	39	60	49	68
25	95	111	27	24	68	72	71	78
26	176	164	59	44	117	120	66	73
27	165	162	135	130	30	32	18	20
28	141	120	83	58	58	62	41	51
29	27	30	10	12	17	18	62	60
Mean	168	162	71	69	97	92	58	58
s.d.	114	84	52	46	73	46	13	12

*All volumes are expressed in ml.
†EDV = End-diastolic volume.
‡N = Nuclear.
§C = Contrast.
¶ESV = End-systolic volume.
**SV = Stroke volume.
††EF = Ejection fraction %.

tally determined coefficient, good correlations were obtained for end-diastolic volume (r = 0.98), end-systolic volume (r = 0.94), stroke-volume (r = 0.90), and ejection fraction (r = 0.87). However, overestimation of volumes in relation to contrast ventriculography would result by 8% (end-diastolic), 7% (end-systolic), and 8% (stroke-volume). Larger s.e.e. would also result for end-diastolic (31 ml) and end-systolic volumes (18 ml).

Intraobserver variability

The raw data, correlation coefficients, and t-statistics between two determinations of radionuclide volumes by the same observer, 2 mo apart, are shown in Table 2. Good correlations ($p < 0.0001$) were found. The end-diastolic volume differed by 7.5%, the end-systolic volume by 15%, the stroke volume by 4%, the cardiac output by 3.2% and the ejection fraction by 5% (three ejection fraction units).

The differences between end-diastolic volume, end-systolic volume, and ejection fraction, although small, were significant. However, the differences in stroke volume and cardiac output were not significant (Table 2). The measured left ventricular depths in Day 1 compared with Day 2 were 8.41 ± 1.1 compared with 8.45 ± 1.0 cm (pns), respectively. The measured backgrounds on Day 1 compared with Day 2 were 83 ± 28 compared with 83 ± 25 counts/pixel (pns).

In 29 studies, one observer manually redrew the left ventricular ROI, while keeping the same background and the same left ventricular depth. The volumes obtained

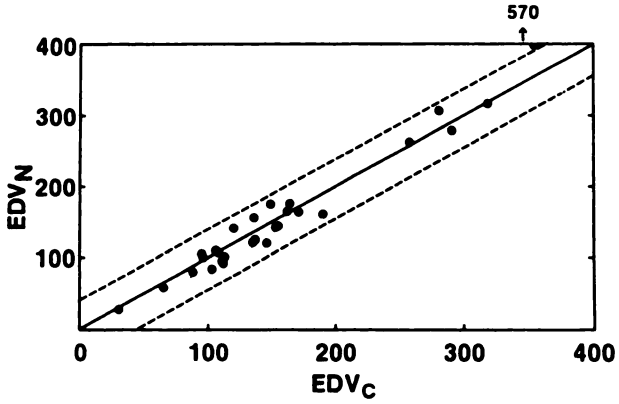

FIGURE 3
Correlation betwen nuclear (EDV_N) and contrast (EDV_C) end-diastolic volumes in patients. $EDV_N = 1.009 \times EDV_C$; $r = 0.98$, ; < 0.0001; s.e.e. = 16.4 ml

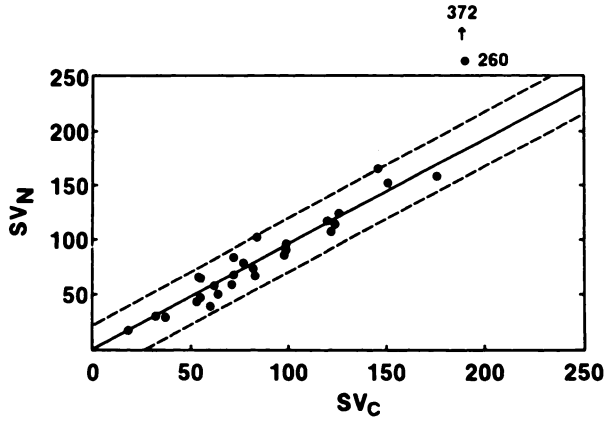

FIGURE 5
Correlation between nuclear (SVN) and contrast (SVc) stroke volumes in patients. $SV_N = 0.959 \times SV_c$; $r = 0.96$; $p < 0.0001$; s.e.e. = 10.6 ml

differed only slightly using the two ROIs: end-diastolic volume = 176 ± 72 compared with 174 ± 71 ml, pns; end-systolic volume = 72 ± 38 compared with 70 ± 38ml ($p < 0.02$); stroke volume = 103 ± 45 compared with 103 ± 47ml, pns; cardiac output = 6.6 ± 2.6 compared with 6.6 ± 2.6 l/min; and ejection fraction = 59 ± 10% compared with 60 ± 11%, pns.

In the 15 studies processed using "high" and "low" backgrounds, increasing the background value by an average of 19.3%, resulted in the following changes in the data: End-diastolic volume decreased by 23%, end-systolic volume by 28%, stroke volume by 19%, cardiac output by 20%, and ejection fraction increased by 5% (+2.6 ejection fraction units). Decreasing the background value by an average of 14.7% increased the end-diastolic volume (+15.3%), end-systolic volume (+22%), stroke volume (+12%) and cardiac output (+12%); and decreased the ejection fraction (−2.7% or −1.6 ejection fraction units).

Interobserver variability

The raw data, correlation coefficients, and t-statistics of volumetric data between the two observers in 21 patients are shown in Table 3. The correlation coefficients between the two observers were high for all variables. The measured distances from the left ventricular center to the camera detector's head varied by an average of 7.7% between the two observers (8.6 ± 1.6 compared with 8.0 ± 1.9 cm, $p < 0.0005$).

The end-diastolic volume differed by 16%, the end-systolic volume by 8.5%, the stroke volume by 21.7%, the cardiac output by 21%, the ejection fraction by 5%. These differences were all significant at the $p < 0.05$ level or below with the exception of the end-systolic volume changes, which were not significant ($p = 0.07$).

The left ventricular depths for Observer 1 and Observer 2 were, respectively, 8.6 ± 1.6 and 8.0 ± 1.9 cm ($p < 0.0005$). The values were consistently lower for Observer 2; as a consequence, the measured volumes were also consistently lower for this observer. The measured backgrounds differed by 6% between the two observers (86 ± 21 and 91 ± 28 counts/pixel, pns).

DISCUSSION

Our investigation was designed to explore the accuracy of a nongeometric radionuclide technique to measure true

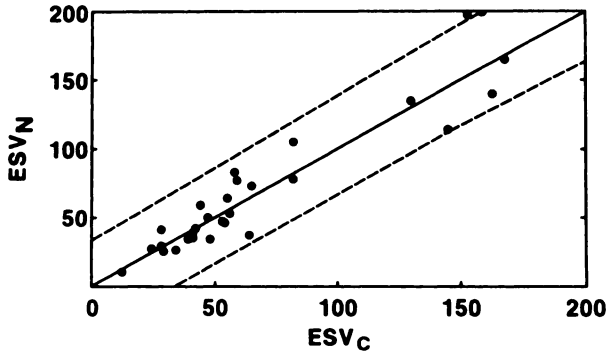

FIGURE 4
Correlation between nuclear (ESV_N) and contrast (ESV_C) end-systolic volumes in patients. $ESV_N = 1.037 \times ESV_c$; $r = 0.95$; $p < 0.0001$; s.e.e. = 17.1 ml

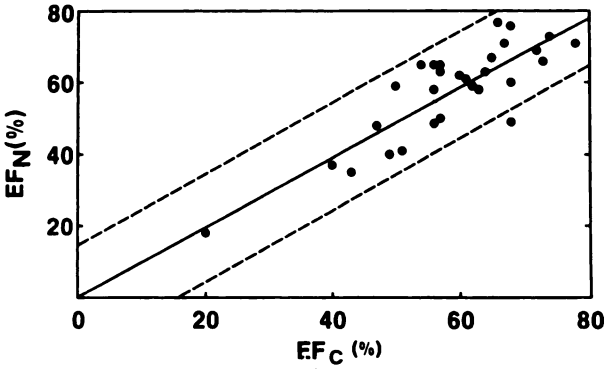

FIGURE 6
Correlation between nuclear (EF_N) and contrast (EF_C) ejection fractions in patients. $EF_N = 0.983\ EF_c$; $r = 0.85$, $p < 0.0001$; s.e.e. = 7.4

TABLE 2
Intraobserver Variability of Radionuclide Volumes

Item	EDV†	ESV‡	SV§	EF¶	CO**	BG††	LV‡‡Depth§§
Observer 1-A	145 ± 70	52 ± 33–	92 ± 53	64 ± 12	6.2 ± 3.0	83 ± 28	8.41 ± 1.1
Observer 1-B	156 ± 71	59 % 28	96 ± 50	61 ± 9	6.4 ± 3.0	83 ± 25	8.45 ± 1.0
Difference	11 ± 20*	7 ± 15*	4 ± 13	−3.2 ± 6.1*	0.2 ± 1.0	.3 ± 7.0	0.06 ± .2
r	0.88	0.92	0.89	0.93	0.89	0.91	0.93

*All volumes are expressed in ml; $p < 0.05$.
†End-diastolic volume.
‡End-systolic volume.
§Stroke volume.
¶Ejection fraction (%).
**Cardiac output (1/min).
††Background (counts).
‡‡Left ventricle.
§§LV depth expressed in cm.

left ventricular volumes. With this aim, in vitro and in vivo experiments were performed. In the in vitro experiments, we confirmed a logarithmic relation between count-rate and the attenuation distance from the source to the camera's detector head. This relationship holds for a wide range of depths, including the expected range of the depth of the center of the left ventricle in humans, yielding an effective attenuation coefficient of 0.144 cm^{-1}. This coefficient is slightly different than the conventional coefficient of 0.15 cm^{-1} (*9,11,12*) but provides significantly different results due to the exponential relationship. The lower value for the derived coefficient is likely a result of the fact that the conventional coefficient was derived from narrow beam geometry, which is not applicable when imaging a fairly large source, such as the heart, with a scintillation camera, where a significant fraction of the counts accepted within the detector's energy window result from scattered photons. Realizing this, we studied phantom-balloons with a wide range of volume capacities, and were able to show a good correlation between the observed and calculated volumes. An overestimation of 13% was found in these phantom studies. The overestimation was primarily in the larger volumes (> 200 ml) and negligible in the smaller volumes (< 100 ml). This suggests that the attenuation coefficient may vary slightly with volume. Furthermore, the attenuation coefficient is also dependent on window width, camera energy resolution, and exact geometry. Variations in these factors account for the variable reported values for the attenuation coefficients, ranging from 0.086 to 0.15 cm^{-1} (*19-21*). Thus, it may be important that each laboratory establishes its own attenuation coefficients using their particular experimental conditions.

From the in vitro studies, and using the experimentally determined attenuation coefficient, we proceeded to the in vivo studies, in 29 patients undergoing contrast angiography. Over a wide range of left ventricular volumes, a high correlation existed between the two techniques. High correlations were observed for end-diastolic volume, end-systolic volume, stroke volume, and ejection fraction.

TABLE 3
Interobserver Variability of Radionuclide Volumes*

Item	EDV†	ESV‡	SV§	EF¶	CO#	LV††Depth§§	BG¶¶
Observer 1	168 ± 63	71 ± 37	96 ± 41	58 ± 12	6.2 ± 2.3	8.6 ± 1.6	86 ± 21
Obselver 2	140 ± 52	64 ± 34	75 ± 29	55 ± 11	5.0 ± 2.0	8.0 ± 1.9	91 ± 28
Difference	−27 ± 29	−7.0 ± 14	−21 ± 20*	−3.0 ± 4*	−1.2 ± 1.1*	−0.60 ± 0.7*	5.0 ± 7.0
r	0.88	0.92	0.89	0.93	0.88	0.93	0.91

*All volumes are expressed in ml; $p < 0.05$.
†End-diastolic volume.
‡End-systolic volume.
§Stroke volume.
¶Ejection fraction.
#Cardiac output.
††Left ventricle.
§§LV depth expressed in cm.
¶¶Background.

This was true irrespective of the fact that our patients had a variety of left ventricular sizes and function, ranging from normal to severely dilated hearts with depressed function. The values obtained by contrast and radionuclide angiography were virtually identical. However, in the two subjects with the largest end-diastolic volumes there was a much larger difference between the contrast (346 and 355 ml) and radionuclide-determined (570, 400 ml) volumes. Thus, both experimentally and in humans, it appears as if the accuracy of the radionuclide technique is lessened when dealing with very large volumes.

We carefully evaluated the intra- and interobserver variability of our measurements and of the several factors involved in the calculations. As shown in Tables 2 and 3, the standard deviations of the differences in measurements (a parameter of the variability in measurement) are not negligible, particularly for the interobserver analysis. Our data revealed a fairly low intraobserver variability for end-diastolic volume, end-systolic volume, stroke volume, cardiac output, and ejection fraction; the lowest average variability was 3.2% for the cardiac output and the highest 15% for the end-systolic volume. The effect of variable backgrounds was also assessed and confirmed the major importance of the background on the volume determinations. As opposed to the determination of the ejection fraction, where small changes in background have no major effects, in the volume determination, each unit change in background translates into a fraction of a ml in the final volume. However small, some of the differences between two measurements by the same observer were statistically significant. The same observer was remarkably accurate in reproducing the left ventricular depth, the background counts, and the left ventricular edges by manual technique. However, in individual patients, when all these factors are combined, significant variations may occur. Thus, it is unlikely that the radionuclide technique will have enough accuracy to detect small, physiological or pathological changes of the left ventricular volumes. Moreover, when this technique is used to assess changes in volumes during interventions, great care needs to be taken not to consider small changes in volumes as biologically significant. Probably only changes above and beyond the observed variability should be considered significant.

A high interobserver variability was generally found in our study. Although good correlations were seen between the volumes measured by the two observers, the differences between paired measurements were all statistically significant, except for the end-systolic volumes. The lowest difference was 5% for the ejection fraction; the highest 21.7% for the stroke volume. The calculated left ventricular depth was consistently higher for one of the observers; consequently, his volume determinations were also consistently higher. The background count determinations were slightly lower (6%) for one observer (pns). The left ventricular depth was significantly different between the two observers and accounted for most of the differences in volume measurements. This difference, which is due to the observer's definitions of the center of the attenuation-marker and the geometric center of the left ventricle, could theoretically be improved by totally automatic, computer-determination of left ventricular depth. Using a smaller point source as the left ventricular marker could also be beneficial.

Previous investigators have reported on different techniques to measure left ventricular volumes by radionuclide angiography. Earlier techniques used geometric assumptions similar to the ones developed for contrast angiography (*1-5*). More recently, count-based methods were introduced (*7,9-12*) and found to be more accurate than the geometric methods (*11*). Links et al. (*9*), were the only other investigators to perform phantom experiments. In their in vitro model, a good linear correlation was found between the calculated and true volumes. In our study we have confirmed these in vitro experiments. In addition, we established a logarithmic relationship between the attenuation distance and detected counts, obtaining an attenuation coefficient more suitable for the model used. Links et al. also studied 35 patients with both radionuclide angiography and single-plane contrast angiography. Good correlations were found for end-diastolic volumes and end-systolic volumes using both techniques, similar to ours. Although no systematic differences were found between the two techniques, their radionuclide angiographic end-diastolic volumes had higher s.e.e (36 compared with 16.4 ml in ours) and higher "average absolute error" (14% compared with 0.4% in ours). The end-systolic volume, as measured by Links et al. had higher s.e.e. (33 compared with 7.1 ml in ours) and "average absolute error" (26% compared with 0.3% in ours). The intraobserver variability of the volume determinations was studied in 11 patients by Links et al. They found a mean difference of 12 $\pm$ 8% for end-diastolic volume (compared to ours of 7.5%) and 12 $\pm$ 8% for end-systolic volume (compared to ours of 15%). Data on interobserver variability and on the individual factors affecting the variability were not presented.

Starling et al. (*12*) have recently reported on their results in patient studies, using a technique similar to the one of Links et al. (*9*). They studied 27 patients with radionuclide angiography and contrast angiography. Good correlations were found for end-diastolic volume, end-systolic volume and ejection fraction between the two techniques. Their s.e.e. for end-diastolic volume and end-systolic volume were similar to Links' (32 and 31 ml). A significant underestimation of the radionuclide end-diastolic and end-systolic volumes was found by Starling et al. These authors also assessed the intra and interobserver variability of the volume measurements in ten random patients. Good correlation coefficients were found, but the mean error of the measurements and s.e.e. were not reported.

Slutsky et al. (*6*) and Dehmer et al. (*7*) have reported on nongeometrical techniques to measure left ventricular volumes by radionuclide angiography. These investigators did not calculate photon attenuation, but rather assumed it to be uniform. In contrast to our technique, "left ventricular volume index" is obtained, rather than true-volumes, and then converted to absolute volumes by using previously derived regression equations. Although high correlation with contrast angiography was found, a technique which directly calculates the true volumes is more appealing and theoretically more correct, since the attenuation, which varies from patient to patient, is actually measured on each patient. This is probably also more sound theoretically than techniques based on "normalized count rate" and calculations of the left ventricular depth based on patient's weight and height (*10*).

In summary, our data derived from both in vitro validation and patient's studies, indicate that the present technique, using an experimentally determined attenuation coefficient, results in more accurate estimates of ventricular volume compared to previous studies. However, substantial intra- and particularly interobserver variability may exist. The main factor responsible for the variability appears to be the determination of the left ventricular depth. Thus, volumes determination by radionuclide angiography may be particularly useful in assessing the effects of interventions on individual patients, since the left ventricular depth will be constant in the same patient. The interobserver variability can be eliminated by having the same observer analyze the results before and after the intervention in any one patient.

FOOTNOTE

*Technicare systems 420-550 and 420-560 VIP.

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