

Radionuclide Left Ventriculography with the Slant Hole Collimator

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A 30° slant-hole collimator was used during radionuclide ventriculography of the cardiac blood pool to improve imaging of the heart in both the modified left anterior oblique (MLAO) and right anterior oblique (RAO) views. In the MLAO view, with the holes slanted caudally, good separation between the left atrium and left ventricle was achieved, and the septum was displayed without foreshortening. In the RAO view with the collimator flat against the chest there was better resolution of the cardiac apex. The results of ejection fraction and wall motion analysis in these patients correlated well with contrast ventriculography ($r = 0.94$). Combination of the slant-hole collimator, in vivo red blood cell labeling with stannous pyrophosphate, simultaneous collection of all phases of the cardiac cycle, and cine mode display, provide a practical system for the noninvasive measurement of left ventricular performance parameters.

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The importance of left ventricular performance parameters in the diagnosis and management of patients with coronary artery disease has been well established (1,2). Until recently, however, their measurement required invasive investigation with considerable accompanying morbidity. Radionuclide angiography (3-5) has provided a noninvasive alternative that permits sequential display of the cardiac chambers and the great vessels after the intravenous injection of [^{99m}Tc]sodium pertechnetate. With the development of Tc-99m-labeled human serum albumin, this agent was used to investigate left ventricular ejection fraction (6) and left ventricular wall motion (7). Because the albumin space is larger than the blood pool, especially in the adjacent liver, Tc-99m labeling of red blood cells both in vitro (8-12) and, more recently, in vivo (13) may provide an improved radiopharmaceutical for the evaluation of left ventricular performance.

Despite the many improvements in data collection and display, appropriate patient positioning has continued to be a problem, with the detector being a considerable distance from the heart in the MLAO and RAO projections. This communication describes a 30° slant-hole, straight-bore collimator* that can avoid this difficulty. Its use is reported here in the context of an overall clinical study: radionuclide left ventriculography using red blood cells labeled in vivo with Tc-99m. The analyses of ejection fraction and regional wall motion were validated by correlation with findings at contrast angiocardiology and ventriculography.

MATERIALS AND METHODS

Patients. Radionuclide ventriculograms were performed on 22 patients who underwent cineangiographic examination for the investigation of coronary artery disease between February and October of 1976.

Blood labeling technique. A standard pyrophosphate kit containing 2.3 mg of stannous tin was reconstituted in 2 ml of normal saline and administered intravenously 15-35 min before the patient received 10-15 mCi of [^{99m}Tc]sodium pertechnetate. The last two patients reported on here received the equivalent of 700 μg of stannous tin rather than the complete contents of the kit. This continues to be our standard procedure.

Collimator. A 36.5-mm-thick collimator with 7000 2.39-mm square holes was constructed from 0.254-mm lead strips. The line spread function (LSF) of this slant-hole collimator and the associated scintillation camera† was measured using a capillary tube filled with Tc-99m, the active area being about 2.5-cm long. The intrinsic LSF of the scintillation camera was determined using a

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TABLE 1. SYSTEM FWHM AND SLANT-HOLE COLLIMATOR FWHM AS A FUNCTION OF DISTANCE FROM THE FACE OF THE COLLIMATOR FOR THE SLANT-HOLE COLLIMATOR

Distance from collimator (cm)	System FWHM (mm)	Collimator FWHM (mm)
0	8.0 ± 0.2	5.3 ± 0.3
2.5	9.0 ± 0.2	6.9 ± 0.3
5.0	10.6 ± 0.2	8.8 ± 0.3
7.5	13.0 ± 0.3	11.6 ± 0.3
10.0	14.7 ± 0.3	13.5 ± 0.4
12.5	16.6 ± 0.4	15.5 ± 0.4
15.0	19.6 ± 0.4	18.7 ± 0.5

2-mm slot in a thick lead brick. The collimator's LSF in terms of the full width at half maximum (FWHM) was calculated from the equation

$$R_c = \sqrt{(R_s^2 - R_d^2)}.$$

RESULTS

Table 1 lists the performance characteristics of the slant-hole collimator used for this study. The sensitivity of this collimator relative to the low-energy, all-purpose collimator was found to be 1.18 ± 0.01 .

The effective separation of the left atrium and the left ventricle in the MLAO projection can be seen in the radionuclide angiogram (Fig. 1). The ventricular septum is viewed normal to its long axis in the MLAO view using the slant-hole collimator (Fig. 2). This is to be contrasted with the foreshortening seen when using a conventional straight-bore collimator in the LAO view. End diastolic and end systolic images in the MLAO and RAO projection using the slant-hole collimator are illustrated in Fig. 3. Correlation of ejection fraction obtained in the MLAO view during radionuclide ventriculography with contrast ventriculography is illustrated in Fig. 4, with the 95% and 99% confidence limits included. The regression line for the two data sets has an r value of 0.94. Regional asynergy of left ventricular wall motion was detected in seven patients by contrast ventriculography. These patients had a total of 15 asynergic regions, 14 of which were seen with radionuclide

ventriculography. A small region of anteroapical hypokinesis was missed in a patient with an ejection fraction of 66%.

DISCUSSION

For optimal evaluation of left ventricular performance, the left ventricular outline must be well delineated, with no superimposition of the other cardiac chambers. The LAO projection provides separation of the two ventricles, but the left atrium still overlaps the upper part of the left ventricle. The MLAO view (15) partially overcomes this problem but rarely can more than 20° of caudal tilt be achieved because of the physical constraints of modern camera detector heads. The caudal tilt also moves the detector away from the organ of interest, thus compromising sensitivity and resolution (16). Most workers therefore employ the best compromise, the RAO projection. This view separates the atria from the ventricles but has two major disadvantages: the overlap of the right ventricle, and again increased distance between the detector and the heart. LeFree et al. (personal communication) used the 20° slant-hole tomographic collimator in an attempt to overcome this problem. Reese et al. (17) used the tomographic collimator for radionuclide ventriculography in the MLAO position, but the extra caudal tilt required to achieve optimal differentiation between the left atrium and the left ventricle results in a physical separation between the collimator and the patient. These problems have been largely overcome by using the 30° slant-hole straight-bore collimator, which allows the MLAO view to be obtained with complete resolution of the left atrium and the left ventricle while the collimator face is against the chest wall. The 30° angulation was chosen from experience with contrast ventriculograms in the RAO projection. The MLAO projection also views the septum normal to its longitudinal axis and provides optimal separation between the distribution of the left anterior descending artery and that of the left circumflex artery. This is of particular importance when evaluating the regional effects of coronary artery disease.

Scintigraphic images of the cardiac blood pool are diffuse, with low contrast in comparison with some other nuclear medicine procedures, for example bone scanning. This results in a low peak information density, so that for good quality scintiscans a large number of counts must be collected. At the same time, we believe resolution requirements are less critical. Therefore we have designed our slant-hole collimator with relatively high sensitivity at the expense of some loss in resolution.

Radionuclide left ventriculography with the slant-hole collimator permits an accurate measure of ejection fraction at equilibrium and a qualitative assessment of regional changes in ventricular volume.

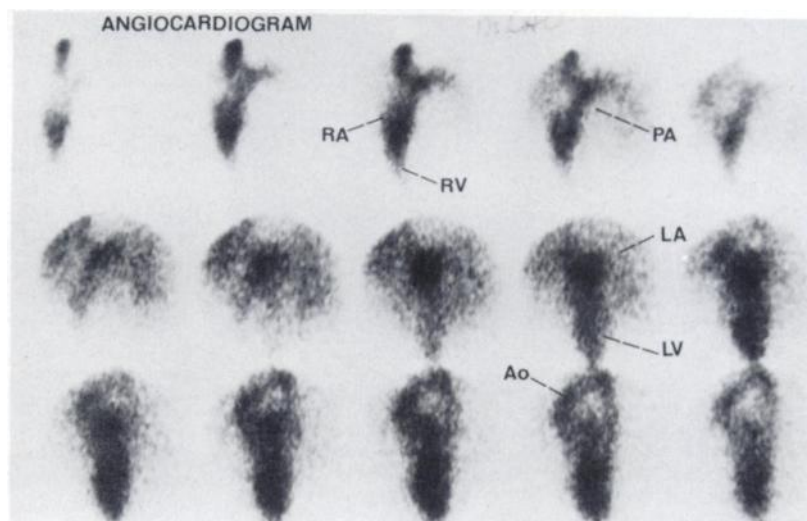


FIG. 1. First pass radionuclide transit in MLAO view, at one frame per second. The nuclide can be clearly seen entering left atrium by eighth frame. Note separation between left atrium and left ventricle.

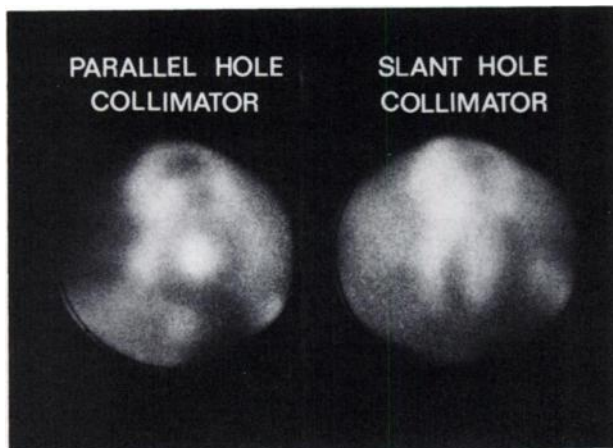


FIG. 2. Ungated image of cardiac blood pool in patient with aortic stenosis and left ventricular hypertrophy. Both straight-bore, parallel-hole collimator and straight-bore, 30° slant-hole collimator were positioned in LAO projection. In both images camera head was positioned flat against chest. Due to slope of chest this provided about a 15° caudal angulation.

Time-activity histograms over the representative cardiac cycle provide high resolution data on temporal features of left ventricular contraction. The use of the 30° slant-hole collimator obviates the positional problems associated with conventional collimation.

where R_c = FWHM of the collimator LSF; R_i = FWHM of the LSF

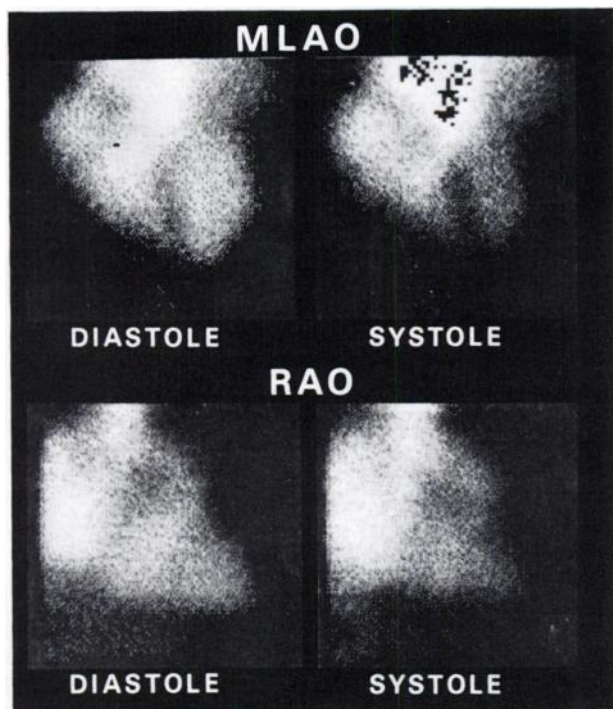


FIG. 3. Radionuclide ventriculogram in normal patient using 30° slant-hole collimator. End systole and end diastole are shown in both MLAO and RAO projections. All views have a lower threshold of 30% and the MLAO systolic image has an upper threshold of 90% to make it comparable with the diastolic image. Cine mode display facilitates identification of cardiac structures, particularly in RAO view where right heart overlaps the left.

EJECTION FRACTION ANALYSIS

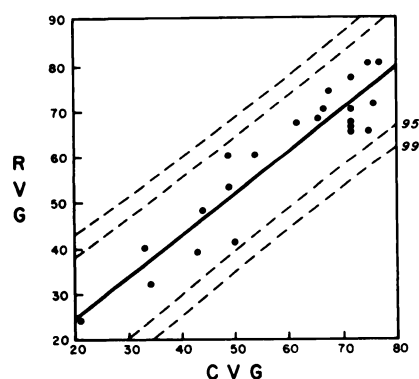


FIG. 4. Correlation of ejection fraction (%) obtained by radionuclide ventriculogram (RVG) with that from contrast ventriculography (CVG). Confidence limits of 95% and 99% (2nd and 3rd standard deviation) are shown. Regression formula is given by $y = 0.90x + 6.3$.

for camera and collimator; and R_i = FWHM of the camera's intrinsic LSF.

Relative sensitivity was measured with a small area source on the slant-hole collimator and compared with a low-energy all purpose collimator.†

Data collection. Electrocardiographically gated equilibrium imaging was performed in the manner originally described by Green et al. (14). Precordial ECG leads were fed through a simple difference amplifier to one of the standard analog-to-digital inputs (AR11) of the computer system.§ Use of precordial leads and adjustment of the amplifier's high frequency filter eliminated most of the noise in the ECG signal. The amplifier's low frequency filter was particularly useful in removing drift. During both setup and data collection, the ECG was sampled every 10 msec and displayed by the computer. Precordial leads were adjusted so that the R wave was the highest amplitude signal.

List mode data, with a digitized ECG value stored with a time mark each 10 msec, were collected directly on magnetic tape (45 ips, 1600 bpi, phase-encoded). Accumulation of 6 million counts required 10–15 min. As soon as positioning was confirmed, imaging was performed in the modified 45° LAO and 30° RAO view, using the 30° slant-hole collimator.

Data analysis. The ventriculogram list mode data were converted into a series of gated frames. The R wave was identified by a user-selected threshold. Data from the same point in each cardiac cycle were summed to form a composite image representing the average cardiac cycle observed during the period of data collection. Each frame was selected to be a multiple of 10 msec in length, so that for a patient with a heart rate of 60/min, an interval of 50 msec divided the R-R intervals into 20 frames. The reformatting of such a study required 30 min on a PDP 11/20 with 16K words of primary memory ($K = 1024$) and a 1.2 megaword disk. On a diastolic image in the MLAO view, one of us (RFU) outlined a left ventricular region of interest and adjacent background two matrix units wide, from the upper septum around to the true posterior wall. Time-activity histograms were evaluated with regard to the systolic emptying phase and diastolic filling phase of the cardiac cycle, and calculation of the average ejection fraction was made. For wall motion analysis, the study was displayed in cine mode with repetitive imaging of the composite cardiac cycle. The MLAO view allowed assessment of the septal, apical, and posterior walls, and the RAO view the anterior and inferior walls. These five areas were also assessed for the

presence of asynergy on the contrast ventriculogram by an independent observer without prior knowledge of the results of radionuclide ventriculogram analysis.

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FOOTNOTES

* Engineering Dynamics Corp., Lowell, Mass.

† General Electric Portacamera, Milwaukee, Wisc.

‡ Searle Radiographics Pt. 822319, Des Plaines, Ill.

§ Digital Equipment Corp., Gamma 11, Maynard, Mass.

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