BASIC SCIENCES

INSTRUMENTATION

The Bifocal Diverging Collimator: A Means of Simultaneous Biplane Imaging of the Heart During Equilibrium Radionuclide Ventriculography

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We have constructed a bifocal diverging collimator (BDC), capable of simultaneously recording two views of the heart 50° apart on each half of a standard imaging field. In this study, simultaneous two-view blood-pool scans using the BDC were compared with the same two separate views obtained using an all-purpose parallel-hole collimator (PHC), assessing left-ventricular ejection fraction and regional wall motion in 20 patients undergoing contrast left ventriculography (CV). Ejection fraction by BDC correlated closely with PHC (r = 0.94) and with CV (r = 0.88). Regional wall motion was scored qualitatively on a five-point scale from 3 (normal) to −1 (dyskinesis) with an 88% agreement between BDC and PHC for segment scores. The percentages for agreement between BDC and CV, and between PHC and CV, were identical, 79%. A single blood-pool scan acquisition using a new BDC provides information about global and regional left-ventricular function in two planes, comparable with that of a PHC.

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Cardiac blood-pool scanning at rest has been used to assess global and regional left-ventricular function in coronary artery disease (*1–5*). However, since many patients with coronary artery disease have normal left-ventricular function at rest (*6*), images are frequently made during acute interventions, such as exercise stress, to induce ischemia-related abnormalities of left-ventricular function (*7–10*). Because the time spent during an intervention may be brief, as is the case with exercise, only a single projection can be conveniently recorded for tracer studies. Usually the LAO is used so that the left-ventricular ejection fraction can be calculated (*11–15*). However, in coronary artery disease, an equally important aspect of ventricular function is regional wall motion (*16*), whose assessment improves with an increase in the number of views obtained (*17,18*). When only a single view is recorded, prior angiographic studies have suggested that the right anterior oblique is preferred for evaluating wall motion, because more of the left-ventricular wall is exposed (*18*).

To permit more precise portrayal of regional wall-motion abnormalities under stress, we constructed a bifocal diverging collimator (BDC) suitable for use on existing conventional and mobile scintillation cameras. It permits rapid-acquisition imaging, similar to that with all-purpose parallel-hole collimators (PHC), but it records simultaneously two views 50° apart. In this study, the development of this collimator for evaluating global and regional left-ventricular function in patients is presented. Blood-pool images were obtained at rest in two projections using a BDC and PHC in 20 patients also undergoing cardiac catheterization; the images were compared with each other and with left-ventricular cineangiograms in the same patients.

METHODS

Collimator design and phantom testing. The bifocal diverging collimator was constructed to provide images from two views 50° apart. Each half of the collimator has

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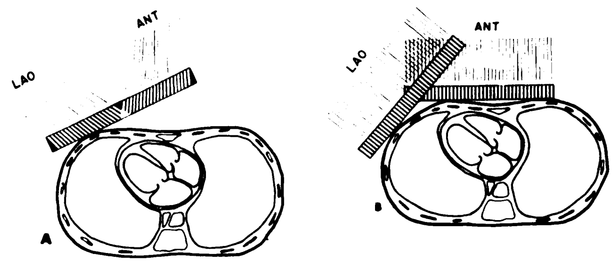

FIG. 1. (A) Cross-sectional diagram of thorax to show two collimator positions required to obtain ANT and 50° LAO views of heart with a parallel-hole collimator. Fine lines beyond collimators show paths of accepted photons. In both projections, a 25-cm field easily covers entire heart. (B) Placement of bifocal diverging collimator to obtain simultaneous ANT and 50° LAO views of heart. Holes in each half diverge at 12°, while the two "axial" holes have 50° between them. Diverging holes at junction must be shortened, which limits unused part of field to 3 cm. To provide good view of septum for LAO half, parts of right heart may need to be excluded.

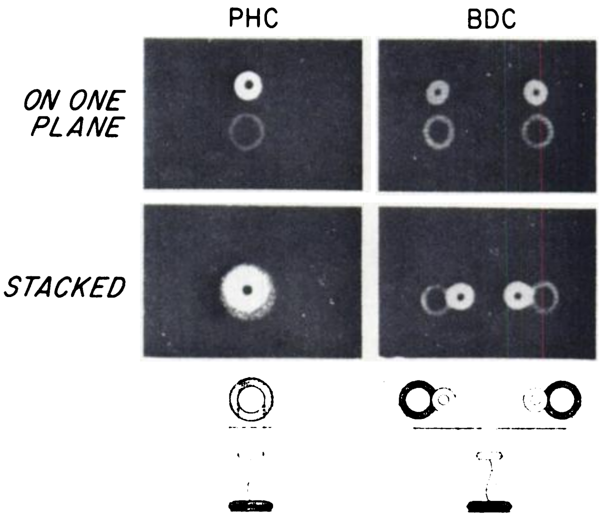

FIG. 2. Sketch of ring phantom (below) as viewed by parallel-hole (PHC) and bifocal diverging (BDC) collimators. Middle row shows corresponding images, with BDC providing two perspectives. Rings are 6 and 10 cm in diameter. Top row shows images with both in same plane; below, planes are 10 cm apart.

holes angled 25° from the detector's axis. These two portions of the collimator split the field of view into two halves. To provide a larger imaging field in each half of the field, each set of holes was set at a diverging angle of 12° from the central ray in each half of the collimator. This is illustrated in Fig. 1. In this manner, the collimator views two perspectives 50° apart. Although the field size of a mobile gamma camera is only 25 cm (12.5 cm for each half), the divergence of the holes permits a larger field (15 cm per view) to be recorded at the usual working distance. As the object of interest is moved farther from the detector surface, larger objects can be imaged in each field of view, but with loss of resolution.

To determine field size, resolution, sensitivity, and degree of spatial distortion of the collimator with depth, phantom studies were undertaken at the surface of the collimator and at distances of 5 and 7.5 cm. Field size was determined using a uniform radioactive source. Resolution and contrast were determined in air using a bar phantom consisting of 3- to 6-cm lead bars separated by comparable spaces. Resolution was expressed as the smallest bar pattern that could be distinguished. In addition, to get an objective assessment of resolution, we calculated a contrast ratio, the numerator being the maximum counts per pixel minus the minimum counts per pixel between the 6-mm bars, and the denominator the maximum counts per pixel (the optimal ratio is 1.0). Sensitivity was determined by measuring the count rate from an uncollimated spot source. Spatial distortion was assessed by imaging two ring phantoms, 6 and 10 cm in diameter, lying in planes spaced 10 cm apart and parallel to the front face of the collimator (Fig. 2).

Patient study. Twenty patients referred for chest pain underwent blood-pool studies at rest within 24 hr of cardiac catheterization and coronary angiography. Of this group, 17 demonstrated significant coronary artery disease and 13 had historical and electrocardiographic evidence of a transmural myocardial infarct.

In each patient, 3 mg of stannous pyrophosphate were given intravenously, followed in 30 min by 20 mCi of pertechnetate (Tc-99m) for the in vivo labeling of red blood cells (*19*). Ten minutes later, supine resting blood-pool studies were obtained in the anterior and 50° LAO projections using the following: (a) a simultaneous 2-min biplane study with the BDC positioned at 25° LAO; and (b) two separate 2-min views with a PHC. For both BDC and PHC LAO studies, the obliquity that optimized visualization of the interventricular septum was used. The emissions were collected with a mobile scintillation camera, a mobile computer system, and an electrocardiographic physiologic synchronizer, using 14 frames for two-thirds of the cardiac cycle. The same frame timing was used for the BDC and PHC studies. The PHC data were collected in a 32 × 32 format and interpolated to 64 × 64 for viewing. BDC acquisition was in a 64 × 64 format because of the miniaturization caused by the collimator.

In order to show that thallium-201 myocardial images could also be obtained using the BDC, anterior and 50° LAO images were collected in one patient who had undergone routine stress myocardial imaging with Tl-201, but who had no coronary artery disease.

Contrast left ventriculography (CV) in the 30° right anterior oblique projection, using 35-mm cinematography at 60 frames per sec, was performed at catheterization in all 20 patients. Twelve patients also had CV in the 60° LAO projection.

The left-ventricular ejection fraction was determined by two independent observers unaware of the results of the cardiac catheterization. Area-length analysis of the

30° right anterior oblique projection was used to determine the ejection fraction by CV (*20*). A semi-automatic edge detection program with varying regions of interest in the LAO view was used to determine ejection fraction on the blood-pool scans. For comparison of techniques, the values of the two observers were averaged. Individual values were analyzed to determine interobserver variance using a two-way analysis of variance.

The left-ventricular wall was divided into three equal segments in each projection: anterolateral, apical, and inferior segments in the anterior radionuclide studies or right anterior oblique CV; and septal, apical-inferior, and posterior segments in the LAO view. Segmental left-ventricular wall motion by both scintigram and ventriculogram was graded by three independent observers using a subjective five-point scale: 3 = normal, 2 = mild hypokinesis, 1 = severe hypokinesis, 0 = akinesis, and −1 = dyskinesis, with half points permitted in the grading system. The scores of the three observers were averaged for each segment for comparative purposes, and the individual readings were analyzed for interobserver variance.

RESULTS

The BDC phantom studies indicate that, at the collimator surface, a field of view 15 cm in diameter is defined on each half of the camera field, while at a depth of 7.5 cm, the two fields of view are 22 cm. Although the resolution at the surface for both collimators is 3 mm (3-mm bars separated by 3-mm spaces can be defined), at 7.5 cm, the BDC gives 6 mm whereas the PHC gives 4 mm. Furthermore, the contrast ratio in the 6-mm pattern for the BDC is 0.65, and at 5.0 and 7.5 cm from the surface it falls to 0.31 and 0.18. The corresponding figures for the PHC are 0.77, 0.61, and 0.45. The falloff in sensitivity at a depth of 7.5 cm, compared with that at the surface, was 33% for the BDC compared with a 2% reduction for the PHC. Spatial distortion with depth was evaluated using the ring phantoms illustrated in Fig. 2. There was virtually no distortion in the ring shape with the BDC, although the larger ring is 10 cm farther away from the collimator than the smaller ring.

Figures 3 and 4 show BDC and PHC end-diastolic and end-systolic images, at rest, on two patients from the study, one with a normal left-ventricular ejection fraction (0.62 and 0.65 for the respective collimator) and the other with a reduced ejection fraction (0.31 and 0.37).

The correlation between the values for ejection fraction derived using these two collimators is illustrated in Fig. 5. The coefficient was 0.94 and the slope of the regression line was 0.86, not differing significantly ($P = 0.1$) from unity. When compared with the ejection fraction derived from left-ventricular cineangiography, the correlation coefficients for the PHC and BDC were 0.87 and 0.88, respectively. Although the interobserver variance for BDC was significantly greater than for PHC (0.06 compared with 0.03, $p < 0.01$) the difference was small, and did not differ significantly from CV (0.06 compared with 0.07).

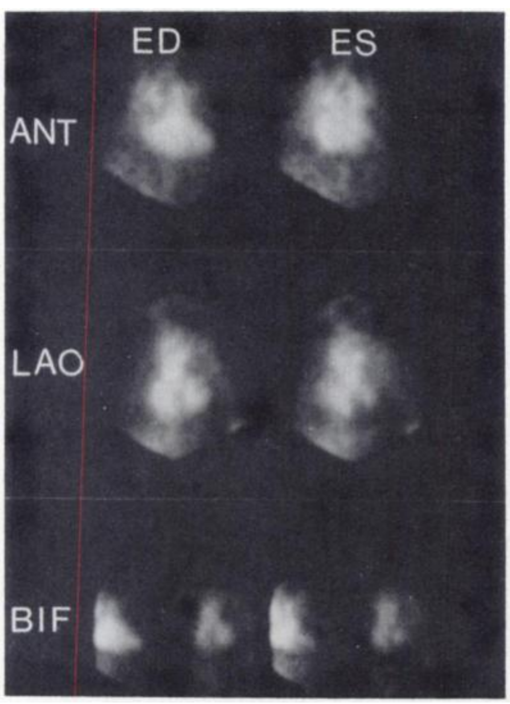

FIG. 3. Two-minute blood-pool images (Tc-PPi) at end-diastole (ED) and end-systole (ES), from patient with normal LV function. Top and middle rows (successive) use conventional collimation; bottom row (simultaneous) uses bifocal diverging collimator.

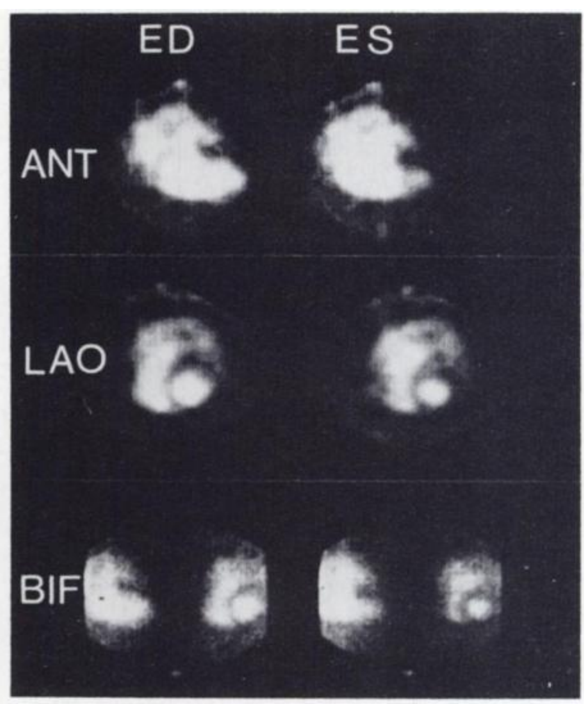

FIG. 4. Images as in Fig. 3, but from patient with reduced LV ejection fraction due to coronary disease.

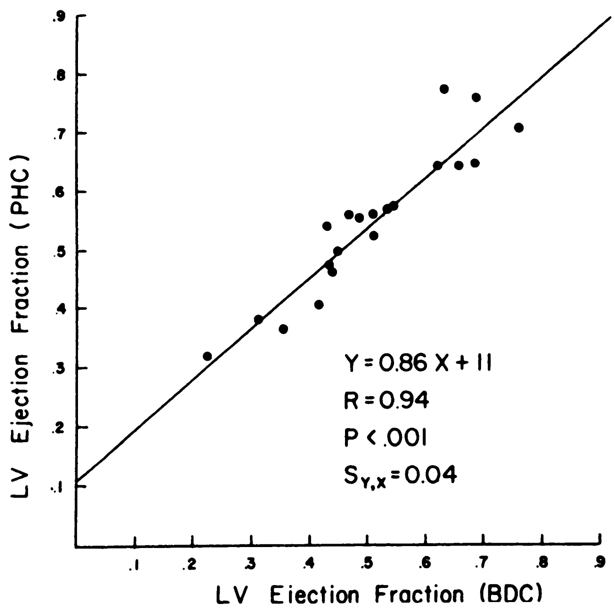

FIG. 5. Scatter plot for 20 comparisons between LV ejection fractions determined with parallel-hole and bifocal diverging collimators. Coefficient of variation around regression line is 4%.

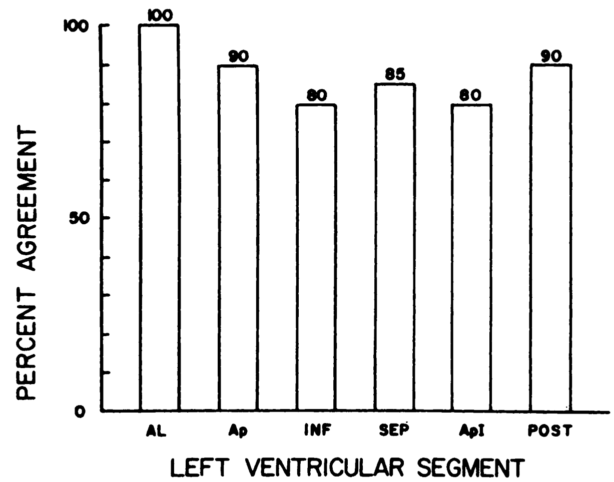

FIG. 6. Comparison of percentage of wall-motion scores in agreement (within one grade) using single-plane versus simultaneous biplane imaging for each of six left-ventricular segments. No significant differences appeared between segments, and overall agreement was 88%.

The wall-motion scores from the PHC and BDC collimators showed a significant correlation, r = 0.77. They agreed in 88% of patients, ranging from 80% for the inferior and apical-inferior segment to 100% for the anterolateral segment (Fig. 6). These differences were not statistically significant. Furthermore, there was no difference between the PHC and BDC in the percentage of myocardial segments in agreement with the angiographic score, or in interobserver variance between PHC, BDC, and CV (Table 1) in the assessments of regional wall motion. Two of the 20 patients had wall-motion abnormalities evident only on the anterior image, but when a patient had an abnormality on the LAO image, one could be visualized on the anterior image as well.

Figure 7 shows an example of anterior and LAO thallium-201 images in a patient without coronary artery disease, made with the PHC and BDC collimators. The corresponding images are similar.

DISCUSSION

Since the assessment of coronary artery disease with radionuclide ventriculography is related to measurement of stress-induced changes in ejection fraction and regional wall motion, comprehensive evaluation of regional ventricular function both at rest and during exercise is important. For this reason, the sensitivity of a blood-pool study in detecting coronary artery disease should be enhanced by the addition of another projection to the LAO during exercise, such as the anterior or right anterior oblique. This study suggests that this is true, since abnormalities of wall motion were found in the anterior view in two patients, these not being evident in the LAO view. Although one could obtain this view by exercising the patient, after recovery from the first study, while imaging in the anterior projection, a second exercise study is both inconvenient and associated with some increased risk. The BDC was developed to view the anterolateral, apical, and inferior segments in addition to the septal, apical-inferior, and posterior segments in the

TABLE 1. INTEROBSERVER VARIANCE OF SEGMENTAL FIVE POINT WALL-MOTION SCORING WITH BLOOD-POOL SCANNING AND CONTRAST VENTRICULOGRAPHY (±1 s.d.)

	Blood-pool scanning		
Left-ventricular segment	Bifocal diverging collimator	Parallel-hole collimator	Contrast ventriculograph
Anterolateral	0.50	0.42	0.36
Apical	0.56	0.48	0.55
Inferior	0.52	0.51	0.54
Septal	0.77	0.72	0.66
Apical-inferior	0.57	0.50	0.43
Posterior	0.45	0.58	0.49

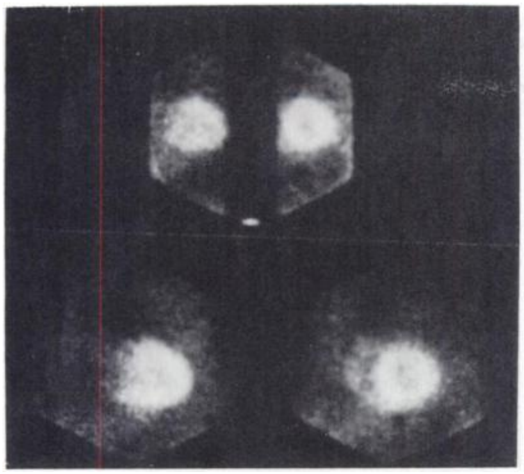

FIG. 7. Simultaneous thallium-201 myocardial images in the ANT projection (left) and 50° LAO (right) using bifocal diverging collimator (above), and comparable but successive single-plane images (below), recorded in the same normal patient.

same time period usually required to assess only the latter three segments. An alternative would be to use the multipinhole technique (*21*). This would eliminate failure of the BDC to use some of the detector surface, due to the joining together of the two segments. The sensitivity of a two-pinhole collimator with 7.5-mm pinholes would be about equal to that of the BDC (*21*).

The BDC is not the first two-view collimator. There have been several recent reports of two-view (biplane) collimators for cardiac imaging made from two sets of parallel holes. The field of view of the biplane collimator is limited to 12.5 cm on a standard-field camera, and this may be too small to see most of the heart in some patients. For this reason, such biplane collimators have been used primarily with large-field cameras (*22–24*). The BDC has two sets of diverging holes, which allow imaging of an object 15 cm in diameter on each half of the 25-cm field of view of both conventional and mobile imaging systems. This, of necessity, is done at some expense of resolution and sensitivity in order to fit most hearts on the screen, as is documented by our phantom data. Furthermore, the lower contrast ratio may affect one's ability to detect small lesions. The use of a BDC can be justified only if these disadvantages are not severe enough to impair adequate assessment of global and regional left-ventricular function. For this reason, we compared biplane blood-pool images with the BDC, collected for 2 min, with conventional anterior and 50° LAO images acquired separately with a PHC, also collected for 2 min. Our study shows that the measurement of left-ventricular ejection fraction with the BDC is as accurate as with a PHC, although the interobserver variability among ejection-fraction determinations was slightly higher with the BDC than with the PHC. The latter finding may be due to a smaller number of picture elements occupied by the left ventricle using the BDC, the lower sensitivity of the BDC, and the algorithm used for edge detection. Nevertheless, the interobserver variance of ejection fraction with the BDC (0.06) was comparable to that of CV (0.07). In addition, the agreement of ejection-fraction values between BDC and PHC, and between either collimator and CV, compares with that found by others (*25–27*). For analysis of left-ventricular wall motion, both the agreement and variance, whether viewed with a PHC or BDC, were equivalent.

There were some unique problems associated with the use of the BDC as compared with the PHC. The width from right-atrial to left-ventricular blood pool in the anterior projection may exceed the width of the anterior half of the field of view. Thus, the apex of the left ventricle, or the lateral border of the right atrium, may be out of sight. For this reason, in patients with cardiac enlargement, it may be necessary to center the anterior image over the left ventricle and exclude part of the right atrial and right ventricular blood pool. Furthermore, with markedly enlarged hearts the right-ventricular blood pool may also not fit on the LAO half of the image. This may preclude assessment of right-ventricular function in patients with cardiomegaly. If knowledge of right-ventricular function during exercise is required, or if the left ventricle is dilated, as in aortic or mitral regurgitation, a PHC in the LAO should be used. Although this is a disadvantage, patients with coronary artery disease and marked left ventricular enlargement would not often be considered candidates for an exercise stress test. Rather, biplane exercise blood-pool studies are most likely to be performed on patients with coronary artery disease and normal or near-normal left-ventricular size. In these patients, the anterior view might even be the only projection in which an abnormality would be detected during exercise, in which case biplane imaging would be useful in improving the sensitivity of this technique in detecting coronary artery disease.

Although the BDC was designed primarily to provide additional information during exercise equilibrium radionuclide studies in patients with coronary artery disease, it may also be useful for other clinical studies, such as simultaneous acquisition of anterior and 50° LAO views for thallium-201 myocardial studies. An example of this is shown in Fig. 7. This saves time and improves sensitivity by detecting transient myocardial defects, which may significantly fill in by the time a second view is completed (*28*). Collected in this way, gated thallium imaging studies, with improved resolution, may be feasible (*29,30*). Furthermore, serial Tl-201 imaging could be performed without moving the patient or the gamma camera, permitting serial quantitative evaluation of thallium kinetics.

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