Left-Ventricular Ejection Fraction and Segmental Wall Motion by Peripheral First-Pass Radionuclide Angiography

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A computerized edge-detection method was developed to obtain radionuclide ventriculograms for analysis of left-ventricular ejection fraction and segmental wall motion from first-pass studies following i.v. injection of radionuclide. The accuracy of this technique was examined in 21 patients undergoing cardiac catheterization. Tc-99m DTPA was injected into an antecubital vein, with data acquisition in the 30° RAO projection by a gamma scintillation camera interfaced to a computer. A computerized profile analysis was used to determine objectively the edge of the left-ventricular blood pool. Time-activity curves were generated, and the ejection fraction was calculated from sequential end-diastolic and end-systolic count rates. The values for ejection fraction correlated well with those obtained by single-plane contrast ventriculography ($r = 0.95$). End-diastolic and end-systolic images were reconstructed from the time-activity curve. To analyse segmental wall motion, the left-ventricular outline was divided into five segments and the motion of each segment was graded qualitatively from 1 to 5. Seventy-five of 105 segments had the same grade as the wall motion determined by contrast angiography, and 102 of 105 were within one grade. ($P < 0.001$). These findings demonstrate the accuracy of this improved technique for objective, rapid, and noninvasive determination of left-ventricular function.


Scintigraphic evaluation of left-ventricular (LV) function is rapidly becoming an important diagnostic tool. Investigators have demonstrated its accuracy in determining ejection fraction using both first-pass (1–8) and equilibrium (9–13) techniques. For the evaluation of segmental wall motion, radionuclide angiograms compared favorably with contrast angiography (11,12,14,15). The gamma-image techniques have been employed to evaluate myocardial infarction (16–19), LV aneurysm (20,21), hypertrophic cardiomyopathy (22), left-atrial myxoma (23), drug intervention (24), postsurgical septal motion (25) and exercise-induced dysfunction (26, 27).

In this study, we have employed a new technique, using an edge-detection computer analysis to obtain radionuclide ventriculograms from first-pass studies following peripheral i.v. injection of tracer. This method allows for rapid, noninvasive, objective analysis of ejection fraction (EF) and segmental wall motion (SWM) in both acutely ill and ambulatory populations.

MATERIALS AND METHODS

Twenty-one consecutive patients (Table 1), ranging in age from 40 to 70 yr (average 57) underwent diagnostic cardiac catheterization and radionuclide...
angiography. Informed consent was obtained for both procedures. The scintigrams were obtained within the 24-hr period preceding or following the contrast angiogram without change in medications between the two procedures. All patients had good-quality contrast LV angiograms with at least one well-opacified normal beat not following a premature contraction. The contrast LV angiograms were performed in the 30° RAO position by intravenous injection of 0.7 mI/kg of Renografin 76 at a rate of 18 ml/sec, with recording on 35-mm film at 30 frames/sec. End/diastolic (ED) and end/systolic (ES) cavity silhouettes were traced by an experienced technician working without knowledge of the radionuclide angiogram. Left-ventricular ED and ES volumes were determined according to the area-length method of Dodge (28), using a 1-cm grid to achieve dimensional calibration. Ejection fractions (EF) were calculated by the expression

\[
\text{EF} = \frac{\text{EDV} - \text{ESV}}{\text{EDV}}
\]

The radionuclide angiograms were obtained by bolus injection into a right or left antecubital vein of 25 mCi of Tc-99m diethylenetriamine penta-acetic acid (DTPA) dissolved in 1 cc of normal saline. Data were acquired with a scintillation camera in a 30° RAO position using a high-resolution parallel-hole collimator. Precordial activity was recorded by a microdot processor at 2 sec per frame during the first 16 sec of the first pass through the heart. Data were stored in, and later processed by, a laboratory computer interfaced to the scintillation camera. Acquisition on 64 x 64 matrices at 25 frames per second for a total of 400 frames spanned passage through the right ventricle (RV) and LV.

**Ejection fraction.** A composite of the entire study was formed by summing the 400 frames (Fig. 1A). A preliminary region of interest corresponding to the entire heart (Fig. 1B) was defined with the computer's light pen, and a time-activity curve of the combined RV and LV was generated (Fig. 1C). From this curve a variable number of consecutive frames (100–200) encompassing the second (LV) peak was summed to determine the LV blood pool without contribution from the right heart. A profile analysis of the entire smoothed LV blood pool (Fig. 1D) was used to ascertain the numeric count level at the point of sharpest ascent as determined by inspection of the absolute count rates from the computer.

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age</th>
<th>Diagnosis</th>
<th>Ejection fraction</th>
<th>Wall motion</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Contrast</td>
<td>Nuclear</td>
</tr>
<tr>
<td>1</td>
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<td>AS</td>
<td>0.58</td>
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<td>2</td>
<td>58</td>
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<tr>
<td>4</td>
<td>60</td>
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<td>CAD</td>
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</tr>
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<td>7</td>
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</tr>
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<td>10</td>
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<td>CAD</td>
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</tr>
<tr>
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<td>CAD</td>
<td>0.44</td>
<td>0.43</td>
</tr>
<tr>
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<td>0.57</td>
<td>0.56</td>
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<td>CAD</td>
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<td>0.49</td>
</tr>
<tr>
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<td></td>
<td>0.55</td>
<td>0.54</td>
</tr>
</tbody>
</table>

* AS = Aortic stenosis; MS = Mitral stenosis; CAD = Coronary artery disease.
† 1 = Normal; 2 = Mild hypokinesia; 3 = Moderate hypokinesia; 4 = Severe hypokinesia; 5 = Akinesia/dyskinesia.
printout. This count level, which defines the transition from background to the LV blood pool, was then used to generate an isocount edge around the LV (Fig. 1E), using the computer's edge program. The plane of the aortic valve was located by identifying the pinching in of the isocount edge in the area of the aortic root, and the edge outline was then filled in with the light pen, resulting in an objectively determined precise LV region of interest (Fig. 1F). A horseshoe-shaped background area was roughly drawn around the LV without encroaching on the aorta (Fig. 1F). Time-activity curves for the LV and background were then generated. The two curves were normalized to represent the same number of channels within ventricular and background areas (Fig. 1G). The first 2 sec of the downslope of this corrected LV curve (7) were then chosen for determination of the ejection fraction by the computer program based on the algorithm:

$$\text{EF} = \frac{\text{ED counts} - \text{ES counts}}{\text{ED counts} - \text{background counts}}$$

The average of the ejection fractions for the beats within the 2-sec period was the radionuclide EF. This and the contrast ejection fraction were correlated by standard regression equations (29).

LV radionuclide angiogram. The LV angiogram was constructed from the corrected LV time-activity curve. Ten to 12 frames selected from two to three ED peaks, and an identical number of frames selected from the ES valleys, were summed to give ED and ES images. The number of frames was limited to 10–12 because the use of a larger number would have required moving away from ED peaks and ES valleys towards intermediate count rates representative of the middle portions of the cardiac cycle. The ED frames had a mean of 79 counts per frame (s.d. = 23); the ES frame count varied with ejection fraction. The composite images were smoothed twice (Fig. 1H and I), and a profile analysis of the ED image was obtained. Using the technique described above, the LV isocount contour was identified and ED and ES edges were constructed and displayed as a two-frame movie. Separate Polaroid photographs were taken of ED and ES frames and then superimposed.

Radionuclide wall motion analysis. The LV outline was divided into five segments (Fig. 2): anterobasal, anterolateral, apical, diaphragmatic, and posterobasal (30). The wall motion of each segment of the superimposed ED and ES images of both the scintigraphic and contrast studies was independently evaluated by two observers in a blinded manner without knowledge of the results obtained by the alternative technique. Each segment was qualitatively classified as either: normal, —1; mildly hypokinetic, —2; moderately hypokinetic, —3; severely hypokinetic, —4; or akinetic and/or dyskinetic, —5. Segments interpreted differently by the two observers were reviewed and a consensus reached. The results obtained by the two techniques were then compared on a segment-by-segment basis and the degree of agreement
between them was analyzed using the kappa statistic (31).

RESULTS

Table 1 lists the results of the radionuclide and contrast techniques. There was excellent correlation of EF, \( r = 0.95; P < 0.001 \) between the two methods, as shown in Fig. 6. The mean heart beats per minute at the time of the gamma and contrast angiograms were 70 \( \pm \) 11 and 75 \( \pm \) 15, respectively. Five patients had rates differing by more than ten beats, and only one differed by more than 15.

The segmental wall-motion analysis is also shown in Table 1. The degree of agreement between the gamma and contrast techniques is shown in Table 2. Of the 105 segment pairs analyzed, 75 were in exact agreement. Twenty-seven pairs differed by one grade, two by two grades, and one by three grades. No more than one segment pair differed by more than one grade in the same patient. The number of segment pairs in exact agreement or one grade apart was 102/105. Analysis by kappa statistic of the degree of agreement between the gamma and contrast techniques yielded a kappa value of 0.54 (\( P < 0.001 \)).

Examples of the radionuclide angiograms with the accompanying traced superimposed contrast angiograms are shown in Figs. 3–5. Figure 3 demonstrates normal wall motion in all segments of both studies. Figure 4 demonstrates areas of mild to moderate hypokinesia in both examinations. Figure 5 reveals areas of moderate and severe hypokinesia and akinesia in both contrast and scintigraphic studies. None of the segment pairs differed by more than one grade.

DISCUSSION

The results of this study demonstrate that accurate EF and SWM analysis can be achieved by first-pass gamma imaging with peripheral i.v. injection of Tc-99m DTPA. The finding of 75/105 segments with the same wall-motion grade, and 102/105 segments within one grade of each other, represents a close agreement between the scintigraphic and contrast techniques. It is also evident that the radionuclide angiogram is not an exact duplicate of the contrast angiogram. The low count rates achieved in the peripheral first-pass study, and the smoothing process employed, make an exact copy unlikely. However, the use of a high-resolution collimator and objective edge-detection analysis may compensate, in part, for the statistical uncertainties of low count rates by minimizing errors that might be introduced with a low-resolution collimator and subjective interplay. In fact, the radionuclide angiogram does accurately localize wall-motion abnormalities and affords a good estimate of their magnitude. Furthermore, the technique was accurate over the entire spectrum of LV angiograms ranging from normal (as in Fig. 3) to severely abnormal (as in Fig. 5).

Precise determination of mitral- and aortic-valve planes still remains a problem but can usually be determined by observing the sequential passage of

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**TABLE 2. DEGREE OF AGREEMENT OF SEGMENTAL WALL MOTION BETWEEN CONTRAST AND RADIONUCLIDE ANGIOGRAMS**

<table>
<thead>
<tr>
<th>Radionuclide angiogram</th>
<th>Mild hypokinesia</th>
<th>Moderate hypokinesia</th>
<th>Severe hypokinesia</th>
<th>Akinesia/dyskinesia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>54</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Mild hypokinesia</td>
<td>11</td>
<td>7</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Moderate hypokinesia</td>
<td>3</td>
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<tr>
<td>Severe hypokinesia</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Akinesia/dyskinesia</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

Kappa = 0.54.  
\( P < 0.001 \).
EF determination utilizing subjective definition of the LV blood pool and demonstrated little interoperator variation. Nonetheless, it would be preferable to minimize any subjective involvement in the acquisition of important clinical data. In many instances, moreover, the LV blood-pool edge cannot be clearly determined subjectively and the edge-detection analysis is of considerable assistance. More importantly, none of these studies reports the ability to analyze segmental wall motion. Jengo et al. (8) report a first-pass technique that accurately determines EF and SWM utilizing isocount contours, but their method requires the use of a pulmonary-artery catheter for SWM analysis. The technique described in this study uses a peripheral i.v. injection and is therefore suitable for use in outpatients, as well as in the acutely ill patient.

The equilibrium imaging techniques offer the advantage of obtaining multiple scans in varying projections with a single tracer injection, and they also achieve count rates more reliable statistically than the first-pass methods do. However, they require a longer period of time for data acquisition, posing problems for the acutely ill patient who may not be able to remain quiescent during the 5–15 min needed for single images. In addition, the inferior segments cannot be accurately evaluated in 30° RAO position in many patients because of RV overlap, a problem not encountered with the temporal separation of RV and LV in the first-pass techniques. The older equilibrium techniques (9,11,12,19,24) relied on geometry-dependent, area-length EF calculations in contrast to the volume-related count-rate changes of this

radioactivity through the cardiac chambers on the microdot images and by noting the pinching in of the isocount contour in the area of the aortic root.

The objective edge-detection analysis distinguishes this study from other first-pass techniques (7–7). Schelbert et al. (7) achieved excellent correlation of

FIG. 3. Superimposed ED and ES outlines of contrast angiogram (A) and radionuclide angiogram (B) of Patient 14. There is normal wide excursion in all regions of both studies.

FIG. 4. Superimposed ED and ES outlines of contrast angiogram (A) and radionuclide angiogram (B) of Patient 20. Hypokinetic areas display close opposition of ED and ES frames. Regions of mild to moderate hypokinesia are present in both studies. See Table 1 for details.

FIG. 5. Superimposed ED and ES outlines of contrast angiogram (A) and radionuclide angiogram (B) of Patient 2. Akinetic areas display superimposition of ED and ES frames. Regions of akinesia, and moderate and severe hypokinesia are present in both studies. See Table 1 for details.

FIG. 6. Linear plot of contrast and scintigraphic ejection fractions. Each closed circle represents an individual patient.
technique, these being independent of deviations from the ideal ellipsoidal shape. The multiple-gated acquisition method (MUGA) (14) is a new technique that uses multiframe analysis, varying count rates and an objective edge-detection analysis. It still requires a relatively long period of time for data acquisition, however, and in many patients the inferior segments cannot be accurately visualized in RAO position.

We conclude that the first-pass technique described in this study offers an accurate means for evaluating LV, EF, and SWV via peripheral i.v. injection of radionuclide. It may be employed in the acutely ill patient and, because of its noninvasive nature, is ideal for the study of nonhospitalized patients.

ACKNOWLEDGMENTS

We would like to thank Dr. Greg Brown and Carol Ross for their assistance with the angiographic analyses, Robert C. Cullison for his assistance with the performance of the radionuclide angiograms, and Dr. Janet Elashoff for the statistical analyses. This work was supported by the Medical Research Service of the Veterans Administration.

REFERENCES

THE SOCIETY OF NUCLEAR MEDICINE
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Anaheim Convention Center
Anaheim, California

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