Left Ventricular Function in Patients With Coronary Artery Disease Assessed by Gated Tomographic Myocardial Perfusion Images

Comparison With Assessment by Contrast Ventriculography and First-Pass Radionuclide Angiography

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Objectives. This study evaluated the use of gated single-photon emission computed tomographic (SPECT) myocardial perfusion images for determination of left ventricular ejection fraction.

Background. Gated SPECT has expanded the applications of myocardial perfusion imaging to include the evaluation of left ventricular size, regional wall motion and regional systolic thickening. Accurate automated or semi-automated methods for quantitation of left ventricular ejection fraction from tomographic perfusion images would provide additional valuable clinical information.

Methods. Rest gated SPECT was performed on the stress distribution of technetium-99m sestamibi, using eight frames per cardiac cycle. Mid-horizontal long-axis and vertical long-axis gated tomographic perfusion images were analyzed after digital matrix inversion, which enhances edge detection, for ejection fraction determination. These ejection fractions were compared with those determined by contrast ventriculography (n = 54, including 45 biplane and 9 single plane) and first-pass radionuclide angiography (n = 38) in patients with coronary artery disease.

Electrocardiographic (ECG) gating of single-photon emission computed tomography (SPECT) has expanded the applications of blood pool scintigraphy. These include the evaluation of left and right ventricular global systolic function, regional wall motion, cardiac chamber volumes and endocardial topography (1–10). However, gated SPECT myocardial perfusion imaging has the additional potential for assessing indexes of myocardial mass, regional systolic thickening and regional perfusion (11–13). Recent improvements in computer processing have made gated SPECT available to many laboratories, generating wide interest in the application of this technique to the quantitative assessment of ventricular performance characteristics (14–16).

The development of technetium-99m–labeled perfusion agents has led to greater interest in obtaining simultaneous perfusion and function information with a single diagnostic study. However, this has required specialized equipment for the evaluation of ventricular function using first-pass radionuclide angiography, which can be followed by tracer localization in the myocardium for perfusion imaging (1%22). Determination of ejection fraction from gated perfusion tomography would therefore be useful to the many laboratories that do not routinely perform first-pass studies.

This study examined the feasibility, reproducibility and accuracy of determining left ventricular ejection fraction from gated tomographic perfusion scans using a computer edge detection algorithm and digitally inverted perfusion images. These data were compared with those of two independent

Results. Myocardial perfusion SPECT image inversion–derived ejection fractions were slightly lower (2.7 ejection fraction units, p < 0.01), and first-pass ejection fractions were much lower (8.0 ejection fraction units, p < 0.001) than those obtained with contrast ventriculography. There was excellent correlation between SPECT and contrast ventriculographic ejection fractions (r = 0.93) over a wide range of ejection fractions (14% to 89%). Good correlation was also observed between first-pass radionuclide angiography and both contrast ventriculography (r = 0.83) and SPECT (r = 0.87). Reproducibility of SPECT image inversion ejection fractions was excellent (intraobserver r = 0.99, interobserver r = 0.93).

Conclusions. Semiautomated ejection fractions can be obtained from gated SPECT technetium-99m sestamibi perfusion images using the image inversion technique. These results are reproducible and correlate well with results of first-pass radionuclide angiography but are closer in value to those obtained with contrast ventriculography.
methods of assessing ejection fraction, first-pass radionuclide angiography and contrast ventriculography.

**Methods**

**Patients.** Post-stress gated SPECT technetium-99m sestamibi (technetium-99m-hexakis-2-methoxy-2-isobutyl isonitrile) myocardial perfusion scintigraphy was performed in 54 patients (40 men and 14 women, mean age ± SD 65 ± 10 years) with coronary artery disease who also underwent, for clinical indications, contrast ventriculographic evaluation within 6 months of the noninvasive study, with no clinically evident ischemic event between these studies. Patients were selected for this comparative study on the basis of having a contrast ventriculogram from which a single beat left ventricular ejection fraction could be ascertained. All patients had evidence for perfusion abnormalities on technetium-99m sestamibi, and 43 of the 54 had scintigraphic or ventriculographic evidence for regional wall motion abnormalities.

**Contrast ventriculography.** Contrast ventriculographic left ventricular ejection fractions were derived from biplane (n = 45) or single-plane (n = 9) contrast ventriculograms, which were acquired at a frame rate of 30 frames/s during iodinated contrast power injection with a pigtail catheter. Ejection fractions were determined from tracings of endocardial borders drawn at end-diastole and end-systole with use of the Sandler and Dodge regression methods (23,24). These data were obtained at a mean interval of 23 days from the SPECT study.

**First-pass radionuclide angiography.** First-pass radionuclide angiography was performed on the same day as the gated SPECT perfusion study in 38 patients with the use of a single crystal high count rate gamma camera fitted with a high sensitivity parallel hole collimator (Elscint Apex 409AG). Anterior projection images were obtained. Technetium-99m sestamibi (9 to 12 mCi) or post-stress technetium-99m diethylene triamine pentaacetic acid (DTPA) (25 mCi) in a volume of less than 1 ml was given by rapid flushing with at least 30 ml of normal saline solution through an indwelling catheter placed in an antecubital (14- or 16-gauge) or external jugular (18- or 20-gauge) vein. First-pass studies were analyzed for left ventricular ejection fraction using previously described standard methods (25-27). Briefly, for calculation of ejection fraction, this software creates a representative left ventricular volume curve by summing frames of several (5 to 15) cardiac cycles, which are aligned by matching their end-diastoles (histogram peaks) and end-systoles (histogram valleys) during the operator-defined levophase of tracer transit. This representative cycle is then corrected for background by using the pulmonary frame method (27) and is interrogated with a fixed region of interest drawn at end-diastole to obtain the final first-pass left ventricular ejection fraction.

**Gated tomographic myocardial perfusion image acquisition.** Stress testing was performed with leg cycle ergometry in 37 patients, treadmill exercise in 13, intravenous dobutamine in 3 and intravenous dipyridamole in 1 patient. Each patient received at peak stress an injection of 23 to 36 mCi of technetium-99m sestamibi, the dose depending primarily on the patient's weight. After a delay of 20 to 60 min to allow hepatic tracer clearance, ECG-gated projections for tomographic reconstruction were obtained, using an Elscint Apex-409AG large field of view gamma camera equipped with a low energy high resolution collimator. A total of 45 projections of 25-s duration at 4° steps and 64 × 64-byte mode images were obtained in the prone position, scanning from right anterior oblique 45° to left posterior oblique 45°. At each projection a total of eight frames/cardiac cycle were acquired.

**Gated tomographic myocardial perfusion image reconstruction.** Images were processed on an Intel-80386 based microcomputer (Elscint Apex-SP1). After collimator sensitivity and center of rotation correction, low pass prefiltered projections were reconstructed into transaxial slices of the myocardium for each of eight frames of the cardiac cycle. Transaxial slices of 2.88-mm pixel thickness were reconstructed using a Butterworth back-projection filter, with a cutoff frequency of 0.5 and order of 14.0. As diagrammed in Figure 1, the transaxial slice sets were then reoriented in cardiac planes, that is, into the short-axis, vertical long-axis and horizontal long-axis planes, for each of the eight frames of the cardiac cycle.

**Figure 1.** Diagrammatic summary of single-photon emission computed tomographic (SPECT) reconstruction process. Planar projections are used to reconstruct rotated transaxial slices by filtered back-projection for each of the eight frames of the cardiac cycle. The transaxial slices are stacked vertically to obtain a three-dimensional data set. These images are reoriented into 4-pixel thick midventricular horizontal and vertical long-axis images. After normalization to a maximal pixel count of 255, the SPECT images are subtracted from a mask image containing 255 counts/pixel. This produces inverted perfusion images that, after manual region of interest placement on the end-diastolic image, enhance endocardial border detection throughout the cardiac cycle. The “counts” produced within the chamber are related to left ventricular size (e.g., wall separation), and they diminish during systolic contraction in proportion to the ejection fraction determined by contrast ventriculography.
Figure 2. End-diastolic and end-systolic frames from gated single-photon emission computed tomographic (SPECT) technetium-99m sestamibi perfusion study, first-pass radionuclide angiography and contrast ventriculography are shown in a patient with coronary artery disease and depressed left ventricular function. A, Vertical long-axis (VLAX) images demonstrate left ventricular enlargement, moderate inferior and severe apical (arrow) hypoperfusion and little change in myocardial thickness or cavity size during systole. B, Inverted perfusion images with computer-derived endocardial edge regions of interest (right). At the apex very few counts are evident on the original image. However, these counts are enough to prevent the automated edge detection from transgressing the myocardial border on the inverted images. The calculated biplane ejection fraction was 15% by gated SPECT. C, Ejection fraction by first-pass images in the anterior projection was 15%. D, Contrast ventriculography (pigtail catheter in left ventricle and pacing wire in the right ventricle, right anterior oblique projection) gave an ejection fraction of 16%.

Gated tomographic myocardial perfusion image inversion. Gated tomographic perfusion image inversion was performed after normalizing both the horizontal and vertical long-axis slice sets to a maximal pixel value of 255. These frames were then subtracted from a mask image containing 255 counts/pixel. This resulted in one myocardial pixel with a value of 0, occurring at end-systole, low counts throughout the myocardium and high counts in the left ventricular chamber. These chamber counts, in theory, would be representative of and proportional to the left ventricular intracavitary blood pool volume within these slices. An example of the gated tomographic perfusion images before and after perfusion image inversion with corresponding first-pass and contrast ventriculographic images is shown in Figure 2.

Semiautomated variable regions of interest were generated on the inverted perfusion data throughout the cardiac cycle by manually placing a region of interest around the left ventricular chamber counts at end-diastole in the midmyocardial area, carefully excluding any background counts and including all inverted chamber counts. Computer-generated regions of interest were constructed for each frame of the cardiac cycle by using a center of mass, combination derivative threshold border detection. Both first and second derivatives of the count distribution profile were calculated in each of eight sectors 45° apart, radiating outward from the center of mass, which on the inverted image is usually central to the left ventricular cavity. The edges are defined where the first and second derivatives are equal to 0. The first derivative edge is loosely fit, whereas the second derivative is very tightly fit around the counts in midchamber. The count threshold, which is the average of these two values, is taken as the edge for a given sector. The threshold value intermediate between the values of any two sectors is derived by linear interpolation. This particular method of edge detection is similar to those routinely employed for gated blood pool equilibrium analysis (28), requiring a gradient of decreasing activity from chamber to walls; therefore, inversion of the perfusion image matrix is required for its use. The ejection fraction was calculated for each
long-axis data set without background subtraction, as the end-diastolic (histogram maximum) counts minus the endsystolic (histogram minimum) counts, divided by the end-diastolic counts. In addition to the ejection fraction, the change in two-dimensional area was also determined by the percent change in the number of pixels in the region of interest from end-diastole to end-systole. The biplane ejection fraction was taken as the numeric average of the horizontal and vertical long-axis values.

Statistical analysis. Linear regression analysis was performed to determine the Pearson product-moment correlation coefficient (r), reflecting the degree of random error, between the ejection fractions obtained with the contrast ventriculographic, first-pass and myocardial perfusion image inversion techniques. The significance of differences between r values were then determined by using the Fisher z-transformation. Systematic error among ejection fractions determined with each technique, as well as their degree of agreement were assessed by using Bland-Altman plots (29,30). Briefly, this method plots the mean of the paired observations of two techniques on the ordinate and the difference between their values on the abscissa. The mean difference between the two techniques and 2 SD above and below this mean are also plotted. This analysis depicts 1) the limits and degree of agreement between the values of ejection fraction obtained with each technique, 2) the degree of bias of one method to give results that are higher or lower than those of the other technique, and 3) the presence or absence of a relation between the degree of underestimation or overestimation and the mean value of the two techniques (e.g., greater overestimation at higher test values). Paired r testing was performed on these data to determine if the ejection fractions obtained with these techniques were substantially different. Data are presented as mean value ±1 SD. A p value <0.05 was considered statistically significant.

Results

Myocardial perfusion image edge detection. Myocardial perfusion scintigraphic results were categorized for the severity of any segmental perfusion abnormality present (e.g., intensity) on a scale ranging from 0 (normal) to 4 (severely reduced segmental perfusion). Perfusion scans demonstrated borderline mild perfusion abnormalities in 3 patients, mild perfusion abnormalities in 13, moderate defects in 14 and severe perfusion defects (i.e., <50% of normal tracer activity) in 24. In patients with nearly absent segmental perfusion, the edge detection algorithm utilized the manually drawn region of interest as that segment's outer border. This procedure presented difficulty only in two subjects whose nearly absent tracer uptake in the inferobasal segment and involving the valve plane required careful manual estimation of the myocardial edge. Despite the widely varying stress perfusion patterns, the edge detection algorithm defined a subjectively reasonable estimation of the endocardial edge in all 54 patients.

Reproducibility of image inversion ejection fractions. Because the image inversion edge detection algorithm is dependent on manual placement of a region of interest around the left ventricular chamber in both long axes, the intraobserver and interobserver variability of the technique were examined in the initial 14 patients (Fig. 3) who underwent this procedure. There was no significant difference between the biplane ejection fractions obtained by the two observers or first and second analysis by the same observer. Both interobserver and intraobserver differences were small, with excellent correlation coefficients (ranging from 0.93 to 0.99), y intercepts near 0 and regression line slopes of near unity. No significant bias or correlation between mean values and differences was found on Bland-Altman analysis. On interobserver analysis, there was one subject with a clinically unacceptable difference of 20 ejection fraction units. In retrospect, this value was due to improper demarcation of the valve plane by one operator, an error that could easily be detected by visual inspection and corrected because the regions of interest at end-systole extended beyond the basal myocardium.

Comparison of SPECT myocardial perfusion image inversion, contrast ventriculography and first-pass radionuclide angiography (Table 1). As shown in Figure 4, there was
Table 1. Correlation Between Contrast Ventriculographic and Radionuclide Methods of Systolic Function Determination

<table>
<thead>
<tr>
<th>Radionuclide Method</th>
<th>r Value</th>
<th>z Value</th>
<th>Regression Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gated SPECT EF</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Biplane</td>
<td>0.93</td>
<td>18.51*</td>
<td>(y = 0.84x + 0.05)</td>
</tr>
<tr>
<td>Vertical long axis</td>
<td>0.91</td>
<td>16.23†</td>
<td>(y = 0.83x + 0.08)</td>
</tr>
<tr>
<td>Horizontal long axis</td>
<td>0.90</td>
<td>14.58‡</td>
<td>(y = 0.84x + 0.03)</td>
</tr>
<tr>
<td>Gated SPECT area change</td>
<td>0.85</td>
<td>11.86§</td>
<td>(y = 0.56x + 0.06)</td>
</tr>
<tr>
<td>First-pass radionuclide</td>
<td>0.83</td>
<td>8.77</td>
<td>(y = 0.63x + 0.13)</td>
</tr>
</tbody>
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*\(p < 0.0226\) versus all four other methods; †\(p < 0.05\) versus gated SPECT area change and first-pass radionuclide angiography; ‡\(p < 0.0066\) versus gated SPECT area change and first-pass radionuclide angiography; §\(p < 0.0020\) versus first-pass radionuclide angiography. EF = ejection fraction; SPECT = single-photon emission computed tomography; x = contrast ventriculography in regression equation; y = radionuclide method in regression equation.

There was good correlation between the percent change in two-dimensional area on biplane SPECT and contrast ventriculography (r = 0.85, z = 11.9). However, this correlation was significantly weaker than the correlation between the contrast and the biplane gated SPECT ejection fraction (p < 0.0001), indicating that the gated SPECT-derived ejection fractions measured are more related to left ventricular volume alterations than to two-dimensional area change in these slices.

The correlation of contrast ventriculography with vertical and horizontal long-axis gated SPECT ejection fractions was also excellent (r = 0.91 and 0.90, respectively, Table 1). The vertical long-axis values were closest in absolute value to those of contrast ventriculography (mean difference 0.4 ± 7.6%, p = NS) than to those of any of the other scintigraphic techniques. However, the inclusion of horizontal long-axis data improved this correlation coefficient to 0.93.

There was good correlation between the first-pass radionuclide angiographic and contrast ventriculographic ejection fractions (r = 0.83, z = 8.77), although this correlation was also significantly weaker than the correlation between the values obtained with contrast ventriculography and SPECT (p < 0.0001). As shown in Figure 5, both the slope of the regression line (0.63 ± 0.07) and Bland-Altman analysis demonstrated progressively increasing underestimation by the first-pass technique of the contrast ventriculographic ejection fractions at the higher range of values (p = 0.003), with a mean underestimation of 8.0 ± 9.5 ejection fraction units.

There was also good correlation between the biplane SPECT and first-pass ejection fractions, with an r value of 0.87 (SPECT 1.1 × first-pass – 0.02, SEE 8.2%, p < 0.0001). As with contrast ventriculography, first-pass values were also lower than SPECT values (mean difference 3.6 ± 8.2%, p < 0.01), with greater difference at higher ejection fractions (r = 0.46, p = 0.002) on Bland-Altman plots.

**Discussion**

This study examined a novel scintigraphic approach to the noninvasive quantitative assessment of left ventricular systolic function, using gated SPECT technetium-99m sestamibi. Using the technique described, accurate quantitation of ejection fraction is feasible in the setting of myocardial perfusion imaging. The values obtained are similar to ejection fraction values obtained from invasive contrast ventriculography. In clinical application, the gated SPECT perfusion technique was performed in these patients for the purpose of assessing...
segmental myocardial perfusion, left ventricular size, regional wall motion, and segmental myocardial thickening with technetium-99m sestamibi, for which eight-frame sampling is sufficient. For quantitation of ejection fraction, a 16-frame format would be preferable, though at a cost of increased time of processing and computer storage space.

The determination of global ejection fraction with the image inversion technique was a time-efficient addendum to the performance of other gated SPECT analyses, requiring an additional 2 to 3 min of processing time. This added clinical information is obtained without additional radiation exposure to or time expenditure by the patient.

Technical aspects of SPECT ejection fraction assessment.

The technique of digital matrix inversion, that is, reversal of a likely dysfunctional segment from the analysis. As at end-diastole or in a dysfunctional dilated ventricle throughout the cardiac cycle, have fewer counts/pixel on perfusion images. After inversion, the result is a larger number of counts in the chamber, which diminishes during systole in proportion to the extent of apposition of the walls (i.e., systolic contractile function). That changes in cavity counts in inverted SPECT perfusion images reflect the volumetric alterations in the ventricle is substantiated by the correlation of gated SPECT–derived ejection fractions with those obtained with standard techniques. This correlation was significantly better than the correlation between the change in two-dimensional cavity area and the ejection fraction by standard methods. This approach also resulted in values that more closely approximated contrast ejection fractions than did those of first-pass radionuclide angiography. Because limited operator intervention is needed, the gated SPECT perfusion image inversion ejection fraction technique had excellent interobserver and intraobserver reproducibility. However, the presence of severe perfusion defects can seriously affect the edge detection. Careful attention to low levels of tracer activity and logical myocardial contours must be employed in these instances, because the manually drawn guiding region of interest must approximate the location of missing myocardium, serving as an outer limit for automated edge searching. Particularly, the lack of regional perfusion in a basal segment can potentially impair the manual estimation of the valve plane, an effect that could adversely influence the ejection fraction assessment by exclusion of a likely dysfunctional segment from the analysis. As with any such technique employing perfusion imaging, adjust-

\[ y = 0.63x + 0.13 \]
\[ r = 0.83, \text{ SEE } = 7.3\% \]
\[ n = 38 \]

\[ y = 0.30x - 0.07 \]
\[ r = 0.44, p = 0.003 \]

Mean Difference = 8.0% ± 9.5%

Figure 5. Same scheme as in Figure 4 shown for first-pass radionuclide angiography (FPRNA) and contrast ventriculography (CATH). There was good correlation, but ejection fractions (EF) of the first-pass study significantly underestimated the ejection fraction values of contrast ventriculography. Bland-Altman analysis demonstrated that this difference between first-pass radionuclide angiography and contrast ventriculography became significantly greater as the ejection fraction increased \( (r = 0.44, p = 0.003) \), meaning greater underestimation of higher ejection fractions.
ments to the guiding region of interest will be needed to track the valve plane and perfusion defects.

**First-pass radionuclide angiography versus SPECT and contrast ventriculography.** Despite the good correlation coefficients, both the gated SPECT and contrast ventriculographic techniques gave significantly higher values than those obtained with first-pass radionuclide angiography. The degree of underestimation by first-pass study was greater at higher values of ejection fraction, as shown by Bland-Altman analysis. In previous studies (32,33) first-pass radionuclide angiography has underestimated the ejection fractions obtained with contrast ventriculography by 12% to 25%. These differences may be, in part, ascribed to the physiologic decline in left ventricular preload on assumption of the upright position for first-pass studies, resulting in lower ejection fraction by the Frank-Starling mechanism. This underestimation may also be due to the use of the currently standard fixed region of interest drawn at end-diastole, which in practice frequently includes counts superior to the valve plane during end-systole, as a result of motion of the cardiac base toward the apex.

**Potential future applications of gated SPECT perfusion imaging.** Published and preliminary studies (14–16,34–36) have attested to the interest in and importance of assessing left ventricular global or regional function, or both, with gated tomographic perfusion images. The additional information on regional and global function contained in combined perfusion-function studies should improve the noninvasive evaluation of ischemic heart disease. Deriving ejection fractions from noninvasive perfusion imaging should result in additional prognostic importance (37–40) and could potentially spare the additional cost and hemodynamic and nephrotoxic risks of performing contrast ventriculography during cardiac catheterization (41,42). In the absence of arrhythmias, no data is lost by ECG gating of perfusion images. These data are quickly reformatted into ungated data by frame addition. The greater photon flux and higher photon energy afforded by technetium-99m-labeled perfusion tracers relative to that provided by thallium-201 provides the opportunity for simultaneous perfusion and function studies, making both gated planar and gated tomographic perfusion imaging possible with adequate counting statistics in multiple image frames.

In some previously published gated tomographic studies (14,15), left ventricular function analysis has been performed with dual-gated (end-diastolic and end-systolic) tomographic myocardial perfusion images. Unlike those studies, in the present study data were acquired throughout the cardiac cycle and edge detection was performed on each frame. No assumptions about the timing of the left ventricular systolic ejection period needed to be made for these continuously gated images.

An area of active investigation (34,35) has been the use of three-dimensional images, rather than biplane slices, for left ventricular intracavitary volume reconstruction throughout the cardiac cycle. This method would have the advantage of not undersampling regional dysfunction in myocardial segments that occur predominantly out of the horizontal and vertical plane. Faber et al. (34) described a surface detector that identifies sets of endocardial (and/or epicardial) points from gated SPECT equilibrium blood pool or technetium-99m sestamibi images. No clinical validation is available at this time to demonstrate the superiority of this technique over biplane methods. Germano et al. (35) also has described a technique for three-dimensional edge definition on technetium-99m sestamibi images using a gaussian fit of myocardial count distribution profiles. This technique was validated against and first-pass radionuclide angiography in 65 subjects and found an excellent degree of correlation ($r = 0.91$), similar to that of the biplane method described herein.

Alternatively, a biplane (vertical and horizontal long axes) method for determining ejection fraction may be particularly useful as it easily appends to regional wall motion analysis and viability assessment (36). In a recently published study, DePuey et al. (16) reported on biplane gated tomography with technetium-99m sestamibi in 30 patients with prior myocardial infarction; they used an eight-frame acquisition protocol and a geometric (Simpson rule) processing approach. Without the use of a count-based method for border definition, regions of interest were manually drawn on each slice. This approach demonstrated good correlation with the reference method of planar gated equilibrium radionuclide angiography ($r = 0.88$). However, with this manually drawn method yielded less intraobserver and interobserver reproducibility (both $r = 0.75$) than that obtained with the semiautomated edge detection method reported herein.

The observations in this report using gated SPECT perfusion imaging also compare favorably with data obtained using a similar approach with blood pool gated SPECT. For example, Corbett et al. (8) demonstrated that in 30 patients who underwent cardiac catheterization, 15-frame gated SPECT equilibrium blood pool images underestimated contrast ventriculographic ejection fractions by 11%, with a correlation coefficient of 0.79 and regression line slope of 0.69, but an excellent SEE of 7.1%, slightly greater than the SEE of the gated SPECT perfusion image inversion technique described herein of 6.2%. Although the Pearson correlation coefficient with gated SPECT perfusion image inversion was higher in our report than in those studies (8,16), this finding predominantly reflects the wider range of validated ejection fractions values described herein.

**Limitations of the study.** The retrospective design of this study and the mean 23-day interval between contrast ventriculography and gated SPECT, with the possible intercurrence of changes in medical condition and medications, may have negatively affected the correlation between the ejection fraction values. The high correlation achieved might have been further improved by prospectively ensuring that patients had the same clinical, hemodynamic and pharmacologic status for both studies.

From a technical standpoint, other than the difficulty in edge detection in the absence of segmental perfusion discussed earlier, a major limitation of this technique is the increment in processing time and computer memory storage space required for gated SPECT perfusion imaging. This limitation should be
offset by the increase in clinical information obtained. The data in this study suggest that a single-plane vertical long-axis assessment of ejection fraction may give results similar to those of contrast ventriculography. However, use of this short-cut to reduce the time required for analysis would risk overestimation of function in patients with isolated septal or lateral wall motion abnormalities that would not be assessed by the vertical long-axis analysis alone.

Another theoretic limitation of this technique is the use of a central core of 8.6-mm thick orthogonal biplane slices, resulting in incomplete sampling in the z direction (i.e., out of the mid-left ventricular plane) of each slice, rather than the full three-dimensional data set. The thickness of these slices is valuable, as the derived ejection fractions correlated better with the results of contrast ventriculography than did the percent change in two-dimensional area of these slices. Also, unlike purely two-dimensional techniques, this method requires no calculations or geometric assumptions about ventricular morphology. The high degree of correlation between the SPECT and contrast ventriculographic ejection fractions over a wide variety of values in patients with a high frequency of regional wall motion abnormalities argues against this theoretic limitation as a limitation in clinical practice.

The use of faster framing rates during acquisition (e.g., >16 frames) is possible but was not explored in this study. As noted earlier, the eight-frame format may be responsible for the slight underestimation of contrast ejection fractions by SPECT (35). Longer duration of acquisition, a larger technetium-99m dose or acceptance of poorer counting statistics in the individual frames would be necessary if faster framing rates were employed. Use of greater sampling frequency (e.g., 24 to 32 frames) would be needed to provide quantitative indexes of left ventricular function that require finer temporal resolution such as left ventricular filling and emptying rates and diastolic time intervals.

Finally, the use of post-stress gated SPECT imaging to assess rest ventricular function, though routinely performed (14–16,33,34), risks the inclusion of postischemic or stunned myocardial segments, which may underestimate true rest cardiac performance. This may be an additional important physiologic source of the variation between contrast ventriculographic ejection fractions and those of gated SPECT.

Conclusions. In conclusion, the gated SPECT myocardial perfusion image inversion technique described herein provides accurate quantitative assessment of left ventricular systolic function in the clinical context of ECG-gated images, which also provide analysis of regional wall motion, systolic thickening, and myocardial perfusion imaging with technetium-99m sestamibi. This technique is highly reproducible, owing to minimal operator intervention and correlates well with contrast ventriculographic and first-pass radionuclide angio-

graphy estimates of left ventricular ejection fraction in patients with ischemic heart disease.

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