Observer Variance in the Qualitative Evaluation of Left Ventricular Wall Motion and the Quantitation of Left Ventricular Ejection Fraction Using Rest and Exercise Multigated Blood Pool Imaging

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SUMMARY Multigated blood-pool imaging (MBPI) at rest and with exercise has been widely used for the evaluation of left ventricular regional wall motion and ejection fraction. Because the precision of these tests depends on interobserver and intraobserver variations in interpretation, we performed the following study. Fifty-nine patients had MBPI at rest and during peak supine bicycle exercise and left ventriculography (LV gram) at rest during cardiac catheterization. Forty-nine patients had significant coronary artery disease and 10 did not. Rest MBPI, exercise MBPI and LV gram regional wall motion were graded by three independent observers. For scoring purposes the left ventricular wall was subdivided into anterolateral, apical, inferior, septal, apical-inferior and posterior walls. Wall motion for both the tracer and contrast studies was scored subjectively on a five-point scale: 3 = normal, 2 = mild hypokinesis, 1 = moderate-to-severe hypokinesis, 0 = akinesis, -1 = dyskinesis. Ejection fraction was determined by two independent observers three times for the LV gram using an area-length method. Results were analyzed by a two-way analysis of variance and expressed as ± 2 SD. Using the five-point scoring system, the estimated interobserver variance for regional wall motion scores ranged from ± 0.60 to ± 1.02 grade for the rest MBPI, ± 0.94 to ± 1.46 grade for the exercise MBPI, and ± 0.66 to ± 0.98 grade for the LV gram, depending on the wall analyzed. The estimated interobserver variance for regional wall motion scores ranged from ± 0.56 to ± 1.08 grade for a change between rest and exercise MBPIs, depending on the wall analyzed. Interobserver variance for the rest MBPI was greater than that for the LV gram for only the septal wall (p < 0.01).

Intraobserver and interobserver variance for ejection fraction determinations were ± 5.8% and ± 6.0%, respectively, for the rest MBPI, ± 9.2% and ± 9.6% for the exercise MBPI and ± 11.0% and ± 11.4% for a change in ejection fraction between rest and exercise MBPIs. When a single observer determined the ejection fraction twice for both the rest and the exercise MBPI, and then compared the averaged rest with the averaged exercise ejection fraction, the interobserver variance was reduced to ± 4.6%. Intraobserver and interobserver variance for the LV gram ejection fraction were ± 6.0% and ± 11.6%. Although intraobserver variance for the rest MBPI and LV gram ejection fraction were not significantly different, interobserver variance for the rest MBPI ejection fraction was significantly less than that for the LV gram (p < 0.005).

Interobserver variance for rest MBPI regional wall motion, and interobserver and intraobserver variance for rest MBPI ejection fraction are comparable to those for the LV gram, except for the septal wall. The results offer objective criteria by which exercise-induced changes in left ventricular regional wall motion and ejection fraction can be interpreted. To minimize the error due to observer variance, exercise-induced changes in ejection fraction should be determined by comparing averaged ejection fractions derived from at least two determinations for both the rest and the exercise MBPI.

MULTIGATED cardiac blood-pool imaging (MBPI) is a noninvasive method of determining left ventricular regional wall motion and ejection fraction. Regional wall motion and ejection fraction on rest multigated images have been used in the setting of acute myocardial infarction, to evaluate congestive heart failure, to diagnose doxorubicin cardiotoxicity and to detect perioperative myocardial infarction. More recently, exercise-induced changes in left ventricular regional wall motion and ejection fraction as assessed by MBPI have been used to diagnose coronary artery disease, to detect early left ventricular dysfunction in valvular heart disease, to differentiate obstructive from nonobstructive hypertrophic cardiomyopathy, to assess the effects of nitroglycerin on exercise-induced abnormalities of left ventricular function and to assess the effects of coronary artery...
bypass on left ventricular function during exercise. Despite the greater availability of the MBPI and its more frequent use for the determination of ejection fraction and regional wall motion at rest and during exercise, the interobserver and intraobserver variances of the methods have not been well defined. The precision of these tests depends on these variances. This study was undertaken to determine the interobserver and intraobserver variance in the qualitatively derived left ventricular ejection fraction and the qualitatively derived regional wall motion at rest and during exercise. Qualitative rather than quantitative assessment of regional wall motion was studied because quantitative techniques have not been widely applied. Consequently, regional wall motion is generally interpreted qualitatively.

Methods

The study group consisted of 59 patients (47 males and 12 females) who had rest and exercise MBPI ordered by their private physicians for the evaluation of chest pain, and who subsequently had cardiac catheterization within 1 week of the tracer study. Forty-nine patients had significant coronary artery disease (≥ 50% diameter stenosis of one or more coronary arteries) and 10 did not. The mean age was 52 ± 9 years (range 31–68 years). There was no evidence of acute myocardial infarction or cardiac decompensation, and no new medication was started during the interval between nuclear imaging and catheterization.

Data Acquisition

Rest Multigated Cardiac Blood-pool Imaging Techniques

Patients were given 3 mg stannous pyrophosphate (Pyrolite, New England Nuclear, N. Billerica, Massachusetts) intravenously, followed 30 minutes later by 20 mCi of technetium-99m pertechnetate to complete the in vivo red blood cell label. After equilibration of the blood pool tracer, patients were imaged in the anterior projection, and in the left anterior oblique projection that displayed the interventricular septum most homogeneously from top to bottom (approximately 50° left anterior oblique). Imaging was performed with a conventional Anger scintillation camera (Ohio Nuclear Series 420 Mobile Gamma Camera) equipped with a high-resolution, parallel-hole collimator. The pulse height analyzer was set at 140 keV with a 20% window. Multigated acquisitions were collected using a mobile nuclear medicine computer system (MUGA-CART, Medical Data Systems, Ann Arbor, Michigan) and an electrocardiographic physiological synchronizer (Brattle Corp., Cambridge, Massachusetts). The cardiac cycle was separated into 28 equal segments. Two hundred thousand counts were collected in each of the 28 frames. Imaging time for each collection ranged from 5–10 minutes.

Exercise Multigated Cardiac Blood-pool Imaging Techniques

After the rest, MBPI patients were exercised in the supine position on a table specially equipped with shoulder restraints, hand grips and attached bicycle ergometer (Engineering Dynamic Corporation Cardiac Stress System, Lowell, Massachusetts) to minimize patient motion during exercise. Electrocardiographic lead II was monitored continuously and leads II, III, aVF and V5 were recorded at 2-minute intervals. A high-resolution collimator was used for imaging to maximize image resolution. Maximal exercise tolerance was determined during an initial exercise test. The exercise test work load started at 25 W and increased by 25 W every 2 minutes. Exercise was symptom-limited by chest pain, shortness of breath or fatigue. A second exercise test was performed 2 hours later at 75% of the maximal work load determined from the initial study. The rationale for the dual exercise test approach was to maximize the duration of exercise at a stable heart rate during image collection. After 1 minute of exercise and stabilization of the heart rate, MBPI was performed in the 50° left anterior oblique projection for 3 minutes during continued exercise. The mean counts/frame was 150,000 ± 29,000 for the exercise MBPI.

Contrast Left Ventriculography

All patients had coronary arteriography and left ventriculography using 35-mm cinematography at 60 frames/sec. The ventriculograms were performed in the 30° right anterior oblique projection. Fifty milliliters of Renografin 76 (E.R. Squibb and Sons, Inc.) containing diatrizoate meglumine and diatrizoate sodium were injected at 15 ml/sec. Thirty-six of 59 patients also had ventriculograms performed in the 60° left anterior oblique projection.

Data Analysis

Wall Motion Analysis

Contrast ventriculograms were assessed by three independent observers unaware of the MBPI results. Motion was scored qualitatively from the movie display on a five-point scale: 3 = normal, 2 = mild hypokinesis, 1 = moderate-to-severe hypokinesis, 0 = akinesia, −1 = dyskinesis. Half-points were used when an observer felt that motion of a segment was intermediate between two grades. The ventricle was divided into anterolateral, apical and inferior walls on the 30° right anterior oblique view, and septal, apical-inferior and posterior walls on the 60° left anterior oblique view (fig. 1).

Rest and exercise MBPIs were displayed side by side as endless-loop movies. Wall motion was determined by three independent observers unaware of the contrast ventriculogram results using the same scoring system as for the contrast ventriculogram. The ventricle was divided into anterolateral, apical and inferior walls on the anterior view, and septal, apical-inferior and posterior walls on the 50° left anterior oblique
view (fig. 1). Although the MBPI and contrast ventriculogram walls were labeled identically, the segments analyzed were not totally comparable due to the differences in obliquities between the techniques.

Ejection Fraction Analysis

Contrast ventriculogram ejection fraction was determined by two independent observers using the area-length method. One of these observers determined the contrast ventriculogram ejection fraction a second time in each patient at least 1 month after the first determination. The observers were unaware of the results of the MBPI ejection fraction. Ejection fraction was calculated from either the right anterior oblique projection alone (n = 23) or from the biplane projections when a left anterior oblique view was also available (n = 36).

Rest and exercise MBPI ejection fractions were calculated in the left anterior oblique projection using the Medical Data Systems MUGE program. A box was positioned to encompass the entire left ventricle in the end-diastolic frame. Beginning at the center, the program searched outward until a matrix point was reached that satisfied one of two criteria: 1) the two-dimensional second derivative was equal to zero, or 2) the number of counts at a matrix point was less than a threshold percent of the peak left ventricular value, which could be adjusted by the observer for each quadrant of the left ventricle. In this manner the left ventricular edge was defined for each frame. The background was determined from the end-systolic frame based on the counts in a segment of lung adjacent to the left ventricle. Based on the region of interest stored for the end-systolic frame, the program constructed a band five matrix points wide located five matrix points to the left of the left ventricle for the background determination. The program calculated an ejection fraction based on counts within the various regions of interest minus background counts. For the purposes of this study, method 1 was defined as the basic program outlined above. Method 2 was defined as the same program plus an option to average the frames in time plus an option to perform a nine-point weighted smooth on the data. Ejection fraction was determined by one observer using method 1 twice and using method 2 once, and by a second observer using method 2 twice and using method 1 once.

Statistical Analysis

Differences between observations were analyzed by a two-way analysis of variance. For the purposes of this study, the total interobserver or intraobserver variance was defined as the error due to observer bias plus the random error inherent in the method. Variations in regional wall motion interpretation and variations in ejection fraction determination were expressed as ±2 standard deviations. Variances between two techniques were compared using an F test. Variances between two observers using the same method were compared with the Newman-Keuls multiple comparison test whenever a significant (p < 0.05) observer effect was detected by the F test embodied in the two-way analysis of variance.

The variance for a change of ejection fraction between a rest MBPI and an exercise MBPI (2SDΔ) was estimated from the formula:

\[2SDΔ = \sqrt{(2SD_{R})^2 + (2SD_{E})^2}\]

where 2SD_{R} was the estimated variance of the rest MBPI and 2SD_{E} was the estimated variance of the exercise MBPI. We could make this approximation because the observer effects were small. The
theoretical variance for a change of ejection fraction between either two rest MBPIs or two exercise MBPIs (2SDΔ) was derived from the formula:

\[ 2SDΔ = \sqrt{2} \cdot 2SD \]

where 2SD was the actual estimated variance of the rest MBPI or the exercise MBPI. The formula made the assumption that the variances of the two studies being compared were the same. The variance for a change in regional wall motion between a rest MBPI and an exercise MBPI was calculated by subjecting the differences in scores (rest minus exercise) to a two-way analysis of variance.

The relationship between MBPI and contrast ventriculography-determined regional wall motion (average of observers) was assessed by calculating the MBPI score minus the contrast score. The relationship was expressed as the mean difference in scores ± 1 SD for each of the six walls. Mean differences for the six walls were compared using a two-way analysis of variance and the Newman-Keuls multiple-comparison test. Standard deviations for the six walls were compared using a test of homogeneity of variances. The correlation between MBPI and contrast ventriculography-determined ejection fraction (average of observers) was assessed using a linear regression analysis.

Results

Interobserver Variance in the Qualitative Evaluation of Left Ventricular Regional Wall Motion

Figure 2 compares the interobserver variance for rest MBPI and rest contrast ventriculography-determined regional wall motion. Interobserver variance for the rest MBPI anterolateral, apical and posterior walls were lower (p < 0.05), septal wall higher (p < 0.05) and inferior and apical-inferior walls not significantly different from the interobserver variances for the corresponding walls on contrast ventriculography. Interobserver variances were significantly higher (p < 0.01) for the rest MBPI septal and apical-inferior walls compared with the anterolateral, apical, inferior and posterior walls. Interobserver variances were significantly higher (p < 0.01) for the contrast ventriculogram apical, apical-inferior and posterior walls compared with the anterolateral, inferior and septal walls. The Newman-Keuls multiple comparison test demonstrated significant differences in wall-motion scoring between two of the three observers for the rest MBPI apical-inferior wall (p < 0.05) and the contrast ventriculogram anterolateral wall (p < 0.05).

Figure 3 compares the interobserver variances for the rest and exercise MBPIs. Interobserver variances for all exercise MBPI walls were greater than those for the corresponding areas on rest MBPI (p < 0.05). Interobserver variances were significantly higher for the exercise MBPI septal and apical-inferior walls compared with the posterior wall (p < 0.01). The Newman-Keuls multiple comparison test demonstrated significant differences in wall-motion scoring between two of the three observers for the exercise MBPI apical-inferior wall (p < 0.01).

Figure 4 lists the interobserver variances for changes in left ventricular regional wall motion between rest and exercise MBPIs. Interobserver variance was significantly lower (p < 0.01) for the posterior wall compared with the septal and apical-inferior walls.

![Figure 2](image-url)

**Figure 2.** Interobserver variance in the evaluation of left ventricular regional wall motion using the contrast left ventriculogram (LV gram) and the rest multigated blood-pool image, expressed as ± 2 SD (five-point scoring system). Left ventricular walls are anterolateral (AL), apical (AP), inferior (INF), septal (SEP), apical-inferior (AI), and posterior (POST). Comparison between walls is discussed in text.
The standard deviations demonstrated in figures 2, 3 and 4 are based on a five-point scoring system. Percent change in score can be calculated and applied to other wall-motion scoring systems by dividing the standard deviation by the number of units in the scoring system and multiplying times 100% (i.e., % of full scale).

Interobserver and Intraobserver Variance in the Quantitative Evaluation of Left Ventricular Ejection Fraction

Table 1 compares the interobserver variance and intraobserver variance for ejection fraction determined by rest MBPI, exercise MBPI and rest contrast ventriculography. Intraobserver variance for ejection fraction determination on rest MBPI was significantly less than that on exercise MBPI using method 1 (no average of frames in time and no weighted smooth) \( (p < 0.005) \) and using method 2 (average of frames in time and weighted smooth) \( (p < 0.005) \). Interobserver variance for ejection fraction determination on rest MBPI was less than that on exercise MBPI for method 1 \( (p < 0.005) \) as well as for method 2 \( (p < 0.005) \). When one observer used method 1 and the second observer used method 2 (method combination), the interobserver variance for ejection fraction determination on rest MBPI was less than that on exercise MBPI \( (p < 0.005) \). Intraobserver variance for the rest MBPI ejection fraction was not significantly different from that for the contrast ventriculogram using method 1, but was significantly greater than that for the contrast ventriculogram using method 2 \( (p < 0.005) \). Interobserver variance for the rest MBPI ejection fraction was less than that for the contrast ventriculogram for method 1 \( (p < 0.005) \), for method 2 \( (p < 0.05) \) and for method combination \( (p < 0.005) \).

Table 1 also lists intraobserver and interobserver variances for calculating a change in ejection fraction between a rest and exercise MBPI, two rest MBPIs or two exercise MBPIs. When method 1 was used to determine the ejection fraction once for both rest and exercise MBPI, the intraobserver variance for an exercise-induced change in ejection fraction was \( \pm 11.0\% \). However, when method 1 was used to determine the ejection fraction twice for both the rest and exercise MBPI and the average values used to calculate the exercise-induced change in ejection fraction, the intraobserver variance was reduced to 4.6%.

Relationship Between MBPI and Contrast Ventriculography

Contrast ventriculographic regional wall motion ranged from normal to dyskinetic, and 34% of walls were abnormal (i.e., hypokinetic, akinetic or
### Table 1. Interobserver and Intraobserver Variance for Left Ventricular Ejection Fraction Determined from 1) Contrast Ventriculograms and Rest and Exercise Multigated Blood-pool Images, 2) for Change ($\Delta$) Between Rest and Exercise Multigated Blood-pool Images, and 3) for Change Between Two Rest or Two Exercise Multigated Blood-pool Images

<table>
<thead>
<tr>
<th></th>
<th>Intraobserver variance</th>
<th>Interobserver variance</th>
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<tbody>
<tr>
<td><strong>LV grams</strong></td>
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<td></td>
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<tr>
<td><strong>Rest MBPI</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) Method 1</td>
<td>6.0%</td>
<td>11.6%</td>
</tr>
<tr>
<td>2) Method 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) Method combination†</td>
<td>6.0%</td>
<td>11.6%</td>
</tr>
<tr>
<td><strong>Exercise MBPI</strong></td>
<td></td>
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</tr>
<tr>
<td>1) Method 1</td>
<td>9.2%</td>
<td>9.6%</td>
</tr>
<tr>
<td>2) Method 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) Method combination†</td>
<td>14.2%</td>
<td>12.0%</td>
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<tr>
<td><strong>$\Delta$ between rest and exercise MBPI</strong></td>
<td>11.0%</td>
<td>11.4%</td>
</tr>
<tr>
<td>1) Method 1</td>
<td>11.0%</td>
<td>11.4%</td>
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<tr>
<td>2) Method 2</td>
<td></td>
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<tr>
<td>3) Method combination†</td>
<td></td>
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<tr>
<td>4) Method 1 — average‡</td>
<td>4.6%</td>
<td>4.6%</td>
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<tr>
<td><strong>$\Delta$ between rest and rest MBPI</strong></td>
<td>8.2%</td>
<td>8.4%</td>
</tr>
<tr>
<td>1) Method 1</td>
<td>8.2%</td>
<td>8.4%</td>
</tr>
<tr>
<td>2) Method 2</td>
<td>12.4%</td>
<td>12.4%</td>
</tr>
<tr>
<td>3) Method combination†</td>
<td></td>
<td></td>
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<tr>
<td><strong>$\Delta$ between exercise and exercise MBPI</strong></td>
<td>13.0%</td>
<td>13.6%</td>
</tr>
<tr>
<td>1) Method 1</td>
<td>13.0%</td>
<td>13.6%</td>
</tr>
<tr>
<td>2) Method 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) Method combination†</td>
<td>20.0%</td>
<td>19.8%</td>
</tr>
</tbody>
</table>

Variance expressed as ± 2 SD.

* $p < 0.05$.

†Method combination = ejection fraction determined by one observer using method 1 and by the second observer using method 2.

‡Method 1 — average = ejection fraction determined using method 1 by one observer on two occasions for both the rest and exercise MBPI. The averaged value for the rest ejection fraction was then compared with the averaged value for the exercise ejection fraction.

Abbreviations: LV gram = contrast left ventriculogram; MBPI = multigated blood-pool image.

The mean differences (mean ± 1 SD) in regional wall motion scores determined from rest MBPI and contrast ventriculograms are listed in table 2. The standard deviations did not differ significantly between the six walls. The mean difference for the inferior wall differed significantly from those of the other five walls ($p < 0.05$).

Contrast ventriculogram ejection fractions ranged from 20–81%. Linear regression analysis for MBPI (method 1) vs contrast ventriculogram ejection fraction yielded the equation $Y = (0.75)X + 13$ ($r = 0.70$, $p < 0.01$, mean error 7.4%, sd 6.2%), where $Y$ was the MBPI ejection fraction and $X$ was the contrast ventriculogram ejection fraction.
Discussion

MBPI-derived left ventricular regional wall motion and global ejection fraction at rest, and with exercise are being used to diagnose and evaluate several cardiac disease states. The interpretations of these tests depend on the interobserver and intraobserver variance.

Qualitatively Derived Left Ventricular Regional Wall Motion

The results of this study demonstrate that the subjective grading of left ventricular regional wall motion on rest MBPI using a five-point scoring system is precise (within 95% confidence levels) to within ±0.60 to ±1.02 grade (±2 SD), depending on the wall analyzed. Subjective grading of left ventricular regional wall motion on exercise MBPI is precise to within ±0.94 to ±1.46 grade (±2 SD), depending on the wall analyzed. Subjective grading of left ventricular regional wall motion on the contrast ventriculogram is precise to within ±0.66 to ±0.98 grade (±2 SD), depending on the wall analyzed. Other investigators have demonstrated a similar interobserver variation in interpreting regional wall motion on contrast left ventriculography.

For both rest and exercise MBPI, septal and apical-inferior walls had the highest interobserver variance. Furthermore, the Newman-Keuls multiple comparison test demonstrated significant differences between two of the observers for the apical-inferior wall for the rest and exercise MBPI. The higher interobserver variance for the MBPI septal wall may have been due in part to the loss of definition of the septum caused by the overlying right ventricular blood pool, because the right side of the septum bulges into the right ventricular chamber. The higher interobserver variance for the apical-inferior wall may have been due in part to the problem of defining two borders with adjoining segments instead of one (i.e., both a septal border and a posterior wall border). This problem of defining the extent of a segment that has two adjoining segments may have also contributed to the higher interobserver variance for the apical and apical-inferior walls on contrast ventriculography.

The higher interobserver variance for all exercise MBPI walls compared with corresponding rest MBPI walls was probably caused by a combination of factors: 1) The exercise MBPIs had a mean of 22% fewer counts/frame compared with the rest MBPIs. The differences reflected an inability to predict the exact time during which the patient was capable of sustaining high-level exercise. 2) Although patient movement during supine bicycle exercise was reduced by shoulder restraints and hand grips, a certain amount of movement was unavoidable. The motion contributed to decreased resolution of the cardiac borders. 3) In many patients with coronary artery disease we have noted an increase in the background lung activity with exercise, perhaps related to exercise-induced pulmonary venous congestion. The resultant decreased target-to-background ratio results in a reduction in image contrast for the exercise MBPI. 4) Finally, irregularities in the cardiac RR interval contribute to blurring, since these data are summed to arrive at a composite cycle. Although imaging began after 1 minute of exercise at a fixed load to minimize changes in heart rate occurring during the image collection, some changes in the RR interval during the exercise image collection are unavoidable.

The interobserver variances in regional wall motion determinations for the rest MBPI were comparable to those determined for the contrast ventriculogram, except for the interventricular septum. Interobserver variance was actually significantly less for the rest MBPI anterolateral, apical and posterior walls compared with the contrast ventriculogram. The comparison of regional wall motion determination by rest MBPI and contrast ventriculogram (table 2) demonstrated a higher mean difference in scores for the inferior wall compared with the other five walls (p < 0.05). The higher mean difference for the left ventricular inferior wall was probably due to the overlying right ventricle in the anterior projection. Standard deviations ranged from 0.30 for the anterolateral wall to 0.80 for the septal wall using a qualitative five-point grading scale. These results demonstrate reasonably good agreement between the two approaches considering the qualitative nature of the scoring system. Previous studies have also demonstrated good agreement between regional wall motion as judged by blood pool imaging and contrast ventriculography. Reasons for the differences between regional wall motion determined by the MBPI and by contrast ventriculography include: 1) differences in imaging projections for the two techniques, 2) differences in the physiologic state of the patient at the time of study, and 3) the effect of contrast medium on regional left ventricular function.

Subjective gradings of exercise-induced changes in wall motion vary considerably between observers. Only left ventricular walls visualized in the 50° left anterior oblique projection are customarily analyzed when performing exercise MBPI because exercise would have to be repeated to obtain images from other projections. To be within 95% confidence limits (±2 SD), exercise-induced changes in regional wall motion scores must exceed ±1.08 grade for the septal wall, ±0.98 grade for the apical-inferior wall, and ±0.56 grade for the posterior wall with a five-point scoring system.
system. Changes of less than these magnitudes fall within the range of interobserver variance and cannot be interpreted with confidence.

**Quantitatively Determined Left Ventricular Ejection Fraction**

Intraobserver variance for the rest MBPI ejection fraction was comparable to that for the contrast ventriculogram using method 1 (non-time-averaged, non-weighted smooth option), but not using method 2 (time-averaged, weighted smooth option). The increased variance with method 2 appeared to be due to random error in the method rather than to observer bias, since interobserver variance was also higher for method 2 compared to method 1. Both interobserver and intraobserver variances for method 2 were also higher than those for method 1 for the exercise MBPI. Thus, the additional processing performed with method 2 appears to introduce additional error into the ejection fraction determination and should be avoided. Since method 1 consistently demonstrated the smaller interobserver and intraobserver variances, we recommend it for the ejection fraction determination.

Using method 1, a single rest MBPI ejection fraction determination is precise to within \( \pm 5.8\% \) (\( \pm 2 \) sd; 95\% confidence level). A single exercise MBPI ejection fraction determination is precise to within \( \pm 9.2\% \) (\( \pm 2 \) sd). For a single observer, a significant change in ejection fraction between rest and exercise MBPI must exceed \( \pm 11.0\% \) (\( \pm 2 \) sd). For different observers, a significant change in ejection fraction between rest and exercise MBPI must exceed \( \pm 11.4\% \) (\( \pm 2 \) sd). However, when a single observer uses method 1 to determine ejection fraction twice for both the rest and exercise MBPI, and then compares the averaged rest to averaged exercise ejection fraction, a significant change in ejection fraction must exceed only \( \pm 4.6\% \) (\( \pm 2 \) sd). These values are similar to those reported by Hamilton and associates.\(^{20}\) Based on statistical analysis of single and group variance, these investigators determined that exercise-induced changes in ejection fraction of \( \pm 6\% \) between the rest and exercise measurements represented a significant change at the 95\% confidence level. These investigators used the mean of three resting measurements as the rest ejection fraction. The number of observers was not specified.

Interobserver variance was significantly higher than intraobserver variance for the contrast ventriculogram ejection fraction. However, interobserver and intraobserver variances were not statistically different for either the rest or the exercise MBPI. Thus, no additional error appears to be introduced into the interpretation of changes in the MBPI ejection fraction when different observers determine the two ejection fractions. Most of the error in the MBPI ejection fraction determination appears to be inherent in the system, with little additional error contributed by observer bias.

Both intraobserver and interobserver variances were higher for the exercise MBPI compared with the rest MBPI ejection fraction determination. As with regional wall motion determination, these differences were probably due to a combination of exercise-related factors including fewer counts/frame, increased patient motion, increased lung background activity and increased effect of RR interval irregularity.

The present study demonstrates a \( \pm 6.0\% \) interobserver variance (expressed as 2 sd) and a \( \pm 11.6\% \) interobserver variance (\( \pm 2 \) sd) for the contrast ventriculogram ejection fraction. Chaitman and associates, using the area-length method, demonstrated a 4\% interobserver variance (\( \pm 2 \) sd) and an 8\% interobserver variance (\( \pm 2 \) sd) for the contrast ventriculogram ejection fraction.\(^{17}\) The difference between the variances in these two studies may be due to the use of biplane and single-plane ventriculograms in our study, and the use of only single-plane ventriculograms in the study by Chaitman and associates. The differences between the two studies are small.

Linear regression analysis for MBPI vs contrast ventriculographic ejection fraction yielded a correlation coefficient of 0.70. Previous reports have demonstrated correlation coefficients ranging from 0.77–0.93.\(^{21,24}\) The lower value in the present study was probably due to a paucity of ejection fraction points in the very high and very low ranges.

**Conclusions**

Interobserver variance for quantitatively determined left ventricular regional wall motion and interobserver and intraobserver variance for quantitatively determined ejection fraction for rest MBPI are at least comparable to those determined for contrast ventriculography, except for the interventricular septum. Interobserver and intraobserver variance for the same determinations on exercise MBPI are significantly higher than those determined for rest MBPI. Single-study determinations of regional wall motion and ejection fraction and changes in determinations between two studies must be interpreted within the limits of interobserver and intraobserver variance. An average of at least two determinations for both the rest and exercise MBPIs should be used when calculating an exercise-induced change in ejection fraction. Using this technique, an exercise-induced change in ejection fraction must exceed 4.6\% to be significant at the 95\% confidence level.

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