Accuracy and Reproducibility of Left Ventricular Ejection Fraction Measurements Using an Ambulatory Radionuclide Left Ventricular Function Monitor

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The accuracy and reproducibility of a new ambulatory radionuclide detector system (the VEST) for ejection fraction measurement has not been fully validated. Thirty-six subjects, (19 volunteers and 17 patients) underwent repetitive bicycle exercise using sequences of both VEST monitoring and gamma camera imaging. A high intraclass correlation was noted for both absolute ejection fraction [0.84 (0.56, 0.95)] and Δ ejection fraction [0.87 (0.63, 0.96)] during repeat VEST monitoring. The intraclass correlation for ejection fraction was comparable for data averaged over 30 sec versus 2 min. These correlations compared favorably to those obtained for assessment of absolute and Δ ejection fraction as derived by gamma camera determination by the same computer operator (intraobserver variability), two different computer operators (interobserver variability), and during repeat exercise using gamma camera imaging. In concordance, correlations between VEST and gamma camera measurements were relatively high for both absolute ejection fraction (0.78 [0.61, 0.88]) and Δ ejection fraction (0.63 [0.39, 0.79]). Thus, the VEST represents a reproducible means of measuring ejection fraction change during dynamic physical activity. Its accuracy in ejection fraction measurements is similar to gamma camera imaging during exercise testing.

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The application of ambulatory electrocardiography in patients with coronary artery disease (CAD) has revealed that episodes of transient ST-segment depression occur commonly (*1*) and are of prognostic significance in patients with CAD (*2*). In the laboratory setting, radionuclide indices are significantly more sensitive than electrocardiography for detecting myocardial ischemia during provocative physical (*3*) or mental stress (*4*). The recent development of an ambulatory device for assessing changes in left ventricular ejection fraction (LVEF) could be of potential clinical importance, since it may be more sensitive than ambulatory electrocardiography for silent myocardial ischemia detection during ambulatory activities. This ambulatory left ventricular function monitor (the "VEST", Capintec, Inc., Ramsey, NJ) permits continuous beat-to-beat assessment of LVEF through utilization of a light-weight scintigraphic detector, held in place by a vest-like garment (*5*). The purpose of this study was to perform a comprehensive analysis of VEST accuracy and reproducibility for measurement of LVEF change.

METHODS

Patient Population

Two groups were selected for our protocol. Twenty healthy individuals were recruited as a volunteer group; one volunteer was excluded due to recorder malfunction. These subjects included 15 men and 4 women with a mean age of 29 ± 7 yr (range 18–44 yr). Nineteen patients, referred to our laboratory for exercise radionuclide ventriculography, because of known or suspected CAD, were recruited as a patient group. One patient was excluded from analysis due to evidence of gross detector movement during exercise and one was excluded because of failure to comply with the exercise protocol. Of the remaining 17 patients, 15 were men and 2 were women. The mean age of this patient group was 58 ± 12 yr (range = 39–75 yr). Each individual signed an informed consent form that had been approved by our Human Subjects Committee.

Test Protocol

Each subject performed repetitive bicycle exercise. Each of the 17 patients exercised twice, once during VEST monitoring and once during gamma camera imaging. Each volunteer also performed exercise during VEST monitoring and gamma camera imaging. Sixteen of the 19 volunteers exercised a third time so that we could assess the reproducibility of EF measurements during repeat exercise using the same scintigraphic technique. Three volunteers were unable to perform this third exercise period due to laboratory time constraints. The volunteers also participated in a protocol designed to assess EF responses to mental stress and daily life activities during VEST monitoring (*6*); this protocol was performed before the exercise protocol so that

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volunteers generally exercised 3–5 hr after the injection of technetium-99m. The 16 volunteers who exercised three times were assigned sequentially to one of two exercise protocols in order to assess EF measurement reproducibility during repeat exercise. If VEST monitoring was used for the first exercise period, then gamma camera imaging was employed during the second and third exercise periods. This sequence was used in 7 of the 16 volunteers. If gamma camera monitoring was used for the first exercise period, then VEST monitoring imaging was employed for the second and third exercise periods. This sequence was used in nine volunteers.

A rest period of approximately 30 min was allotted between the exercise tests to allow heart rate and blood pressure to return to baseline. Initial workloads were set at 200 kpm with the workload increased by 200 kpm every 3 min of exercise. The patients exercised maximally (to exhaustion or moderately severe chest pain) and the volunteers were asked to exercise until they achieved 85% of their maximal predicted heart rate.

Data Acquisition

Radionuclide Ventriculography. Each subject was injected with 25 mCi of technetium-99m in-vitro labeled red blood cells (*7*). Upright bicycle ergometry was used for the exercise portions of the protocol. A mobile gamma camera, equipped with a 0.25 in. sodium iodide crystal, a gating device, and an all-purpose collimator, was then positioned in the left anterior oblique view that best separated the left and right ventricles (approximately 45°). Multiple-gated equilibrium blood-pool scintigraphy was performed by acquisition of 20 frames/cardiac cycle for a total of 2 min per acquisition during the rest period, the last 2 min of each 3-min exercise stage, and the first 2 min immediately postexercise (*7*). The 2-min imaging resulted in approximately 100,000 counts per frame. Cardiac rhythm, ST segments, and heart rate were continuously monitored, with blood pressure obtained at 1–2-min intervals during each stage of exercise, using a standard mercury sphygmomanometer.

Vest Monitoring. The VEST is comprised of a main cardiac detector and an auxiliary background detector. The main cardiac detector consists of a single sodium iodide crystal which is 5.6 cm in diameter with a central aperture diameter of 4.5 cm, a high sensitivity parallel-hole collimator, and two photomultiplier tubes. A plastic vest-like garment was used to hold the detectors in place. The other components of the VEST monitoring system are a 2-lead electrocardiographic monitor, a gating device, a data logger, a cassette recorder, and a micro-computer.

The gamma camera was used to determine the optimal placement of the VEST relative to the chest wall. Using direct camera visualization, an iron marker was used to find the center of the left ventricular blood pool on the screen of the oscilloscope. Electrocardiographic electrodes were placed in an inferior and a V5 position. The VEST garment was placed over the subject's chest and tightened to assure stable contact between the garment and the chest wall. The position of the VEST detector over the left ventricle was modified under gamma camera control, until right ventricular and left atrial overlap were minimized. A 2-min static gamma camera image was obtained to confirm the adequacy of the VEST detector position.

Data Interpretation. The gamma camera LVEFs were determined by two experienced clinical computer operators, blinded to all data, using light-pen assignment of end-diastolic, end-systolic, and background regions of interest (*7*). EF was calculated from stroke counts (background-corrected end-diastolic minus background-corrected end-systolic counts) divided by background-corrected end-diastolic counts.

For the VEST, three quality control steps were performed prior to data analysis. First, a repeat 2-min static gamma camera image was obtained following exercise and compared to the pre-exercise image to determine if there was any change in the position of the VEST detector relative to cardiac structures. Second, a trend plot of the left ventricular and background scintigraphic counts over time was assessed. Sudden shifts in these plots generally signify detector movement. Third, the raw beat-to-beat data were analyzed subjectively to assess the quality of the individual time-activity curves. Except for the one aforementioned patient who was excluded because of gross detector movement, all other studies were deemed to be of adequate quality for analysis by these criteria.

The VEST background count value was determined by matching the initial resting VEST EF value to that obtained by the gamma camera. This background value (ranging from 59% to 81%) was then used throughout the remainder of each individual's VEST data analysis. The VEST radionuclide and heart rate data were averaged over 30-sec intervals for calculating EF values. Four consecutive 30-sec intervals were then averaged to obtain 2-min EF values. These 2-min VEST results were compared to the 2-min data obtained from gamma camera imaging.

Both the absolute values for EF and change from rest values (Δ EF) were assessed for each comparable gamma camera and VEST exercise stage. To assess comparable physiologic data, corresponding data were matched according to similarity in heart rate and blood pressure responses. Data were not assessed if the heart rates varied by greater than 10 bpm, if the systolic blood pressure varied by greater than 20 mmHg, or if induced ST-segment depression varied by greater than 0.5 mm for a given stage of repetitive exercise. A similar matching was used to compare EF data in the nine volunteers who underwent VEST monitoring twice.

In order to assess intra- and interobserver variability for EF, the two computer operators each calculated the rest and exercise EF values for the exercise ventriculographic studies in the group of 17 patients and for the 7 volunteers who performed gamma camera bicycle exercise twice. These analyses were used to compare inter- and intraobserver variability in a relatively more heterogeneous group with respect to EF responses (patient group) to a more homogeneous group (healthy volunteers).

Statistical Methods

All statistical comparisons were made using either the absolute peak exercise EF or the change from rest (Δ EF). Resting EF was determined from the average of two baseline EF determinations. Initially, data were examined separately for patients and volunteers. Since these results were the same as the results for the patients and volunteers combined, the data are presented combined.

Vest Versus Gamma Camera

The Lin concordance correlation coefficient (r_c) (with corresponding 95% confidence interval) was used as an index of the agreement between the two methods of EF determination (gamma camera versus VEST). This index evaluates the agreement between two readings (from the same sample) by measuring the variation from the line of identity (the concordance line) (*8*). A value of 1 indicates perfect agreement.

Reproducibility

Intraclass correlation coefficients (ICC) were derived to examine the variation resulting from: (1) a single technician performing two repeat determinations of EF (intraobserver); (2) two different technicians processing the same EF (interobserver); and (3) a single technician processing the same subject's EF from two different exercise sessions (interexercise). The ICC was derived from the variance terms generated from one-way analysis of variance (*9,10*). The ICC has been characterized as follows: slight reproducibility (0.0–0.20); fair (0.21–0.40); moderate (0.41–0.60); substantial (0.61–0.80); and almost perfect (0.81–1.00) (*9*).

The mean difference (MD) between two EF determinations was used to quantify bias between the repeat measurements. The mean absolute difference (MAD) between two EF determinations was used to measure the magnitude of difference, since changes in either direction are of interest.

To compare the different factors contributing to the total variability of gamma camera EF, a mixed model analysis of variance was used to estimate the variance components corresponding to intraobserver and interobserver differences (*11,12*). Standard deviations are reported because they are easier to interpret since they are expressed in the same EF units.

Hemodynamic data are summarized as mean ± 1 s.d. Confidence intervals (95%) for ICC are given. All significance testing was done at the 0.05 level (two-sided tests). Computations were carried out using BMDP statistical software (2V, 8V, 1D) (*13*) and SAS (*14*).

RESULTS

The hemodynamic responses to exercise in the 19 volunteers and 17 patients are listed in Table 1. The values for peak exercise heart rate and blood pressure responses were similar during the repeat exercise sessions. There was a tendency for resting heart rate to be elevated before the second exercise period in the patient group, whereas resting

TABLE 1
Comparison of Hemodynamic Responses to Exercise

Volunteer group	Exercise #1 (n = 19)	Exercise #2 (n = 19)	Exercise #3 (n = 16)
Rest HR	79 ± 12	79 ± 13	82 ± 12
Peak HR	150 ± 19	153 ± 17	152 ± 19
Rest SBP	120 ± 11	121 ± 11	121 ± 12
Rest DBP	79 ± 8	81 ± 7	81 ± 7
Peak SBP	191 ± 19	195 ± 17	196 ± 18
Peak DBP	91 ± 13	90 ± 13	89 ± 12
Patient group	(n = 17)	(n = 17)	
Rest HR	70 ± 9	78 ± 10	
Peak HR	134 ± 21	132 ± 21	
Rest SBP	134 ± 14	134 ± 16	
Rest DBP	80 ± 13	81 ± 12	
Peak SBP	197 ± 41	194 ± 40	
Peak DBP	86 ± 21	90 ± 16	

HR = heart rate; SBP = systolic blood pressure; DBP = diastolic blood pressure; and p = ns among the exercise periods.

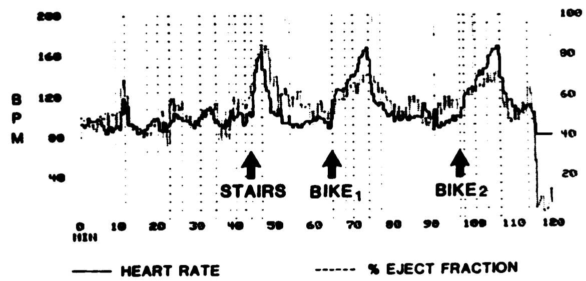

FIGURE 1. A subject example of a VEST EF trend plot during stair climbing and repetitive bicycle exercise. EF (%-dotted line) and heart rate (bpm-solid line) are shown. The scale for EF is on the right (from 20 to 100) and the scale of heart rate is on the left (from 40 to 200). Time, in minutes, is listed on the bottom of the figure. The dotted vertical lines represent event marker activation, typically utilized at the beginning and end of an activity or exercise stage.

heart rates were relatively similar before exercise periods in the healthy volunteer group.

VEST Measurements: Correlations of LVEF During Repeat Bicycle Exercise Sessions

We compared the correlation of EF data in the subgroup of nine volunteers who performed two sequential exercise sessions wearing the VEST. An example of a LVEF trend plot of one subject undergoing the protocol is shown in Figure 1. The correlations for absolute and Δ EF values obtained over 2 min and over 30 sec are shown in Figure 2. A high intraclass correlation was noted for both absolute EF [ICC = 0.84 [(0.56, 0.95)] and Δ EF measurements [ICC = 0.87 (0.63, 0.96)] for the data averaged over 2 min. Similar correlations were noted for the VEST measurements obtained over the shorter 30-sec intervals [both absolute and Δ EF ICC = 0.90 (0.72, 0.90) and (0.72, 0.97), respectively]. Notably, these high correlations were obtained utilizing only the peak exercise EF values, when the most vigorous physical movement would be expected to be present.

Gamma Camera Measurements: Assessment of Intra- and Interobserver Variability and Correlation Between LVEF Camera Measurements During Repeat Exercise Periods and During Repeat Operator Processing

We assessed intraobserver variability of EF determinations by comparing the absolute and Δ EF measurements obtained by two separate computer operators who analyzed rest, peak, and Δ EF for 23 subjects (16 of the 17 patients with suspected CAD and 7 of the volunteers who had undergone repeat gamma camera exercise). The results are shown in Figure 3. Intraobserver variability was low, as evidenced by the very high ICC for the measurements obtained for both computer operators. We also assessed the interobserver variability for these same data between the two computer operators. For this analysis, we averaged the two EF determinations from rest and from exercise for each operator and then compared the summed averages of rest, exercise, and Δ EF in the same sample of patients.

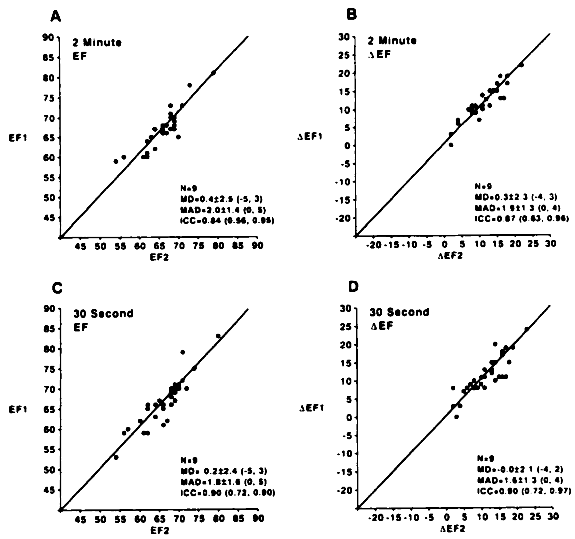

FIGURE 2. Reproducibility of the VEST EF and Δ EF utilizing 2-min summated data (A–B) and 30-sec summated data (C–D). MD = mean difference, MAD = mean absolute difference, and ICC = intraclass correlation. MD and MAD are expressed as the mean ± s.d.; ICC is expressed as the r value (95% CI).

A moderately high ICC [absolute EF 0.83 (0.69, 0.91) and Δ EF [0.84 (0.69, 0.91)] was noted between the two observers. Although the MAD for interobserver EF determination were larger than those observed for the intraobserver determination (absolute EF 4.4 versus 0.7% and Δ EF 4.3 versus 3.2%, respectively), these MAD were still relatively low. The variation in duplicate processing by the same observer was smaller than the variation in processing the same image by two different observers (s.d. absolute EF: 0.1 versus 12.2% and s.d. Δ EF: 3.8% versus 4.5%, respectively).

We next assessed the variability in absolute and Δ EF when seven of the volunteers underwent repeat gamma camera bicycle exercise (Fig. 4A–B). The ICC for Δ EF was relatively low [absolute EF 0.80 (0.40, 0.94), Δ EF 0.48 (0.20, 0.83)]. The MAD were low (absolute EF: 2.4% ± 3.3%; Δ EF 3.1% ± 2.5%). For comparison, we assessed the intraobserver variability for absolute and EF measurements by a single operator (who had previously demonstrated the lowest intraobserver variability). EF measurements from the first exercise test in these volunteers processed twice is shown in Figure 4C–D. ICC for EF now increased to 0.93 (0.74, 0.98) and there was a substantial decrease in the MAD compared to the above-mentioned analysis (absolute EF:1.6% ± 1.4%; Δ EF 2.2% ± 2.1%).

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Correlation Between Gamma Camera and VEST Measurements During Two Exercise Periods

The comparisons for exercise EF measurements derived from the two separate techniques—the VEST and gamma camera—are compared in Figure 5. The concordance correlation coefficients were moderately high, [absolute EF 0.78 (0.61, 0.88) Δ EF 0.63 (0.39, 0.79)]. The ICC were very similar to the concordance coefficients. Larger MAD were noted for the Δ EF measurements for this comparison when compared to all of the prior determinations.

We divided the peak exercise ejection responses into three clinical EF response classifications: a rise ≥ 5%, a fall ≥ 5%, or a "flat" response (absolute change less than 5%). There was concordance between VEST and gamma camera classification in 32 (89%) of the 36 individuals.

DISCUSSION

Assessment of VEST Reproducibility

Our study was designed to assess both the reproducibility and accuracy of VEST measurements of Δ EF. We were most interested in Δ EF rather than absolute EF, since the

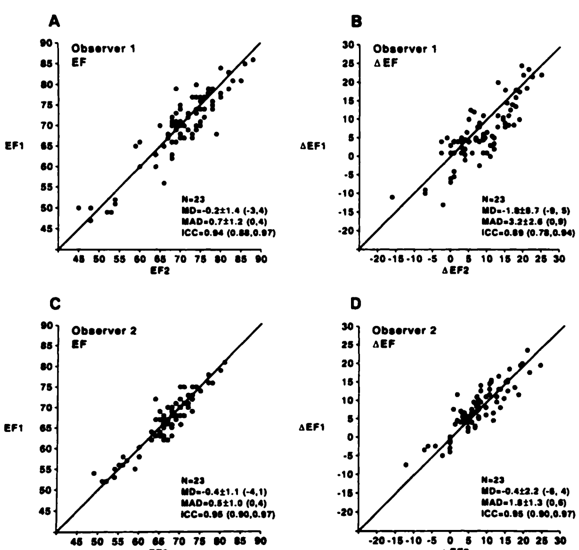

FIGURE 3. Gamma camera EF and Δ EF intraobserver variability for Observer 1 (A–B) and Observer 2 (C–D). Abbreviations are as previously cited.

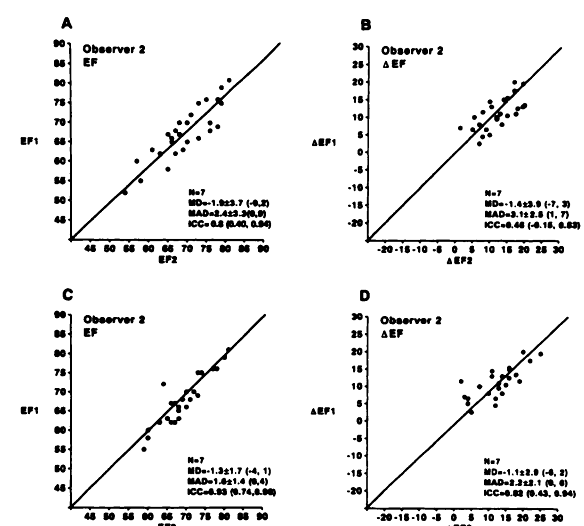

FIGURE 4. Gamma camera EF and Δ EF reproducibility (A–B) and intraobserver variability (C–D) in control subjects. Abbreviations are as previously cited.

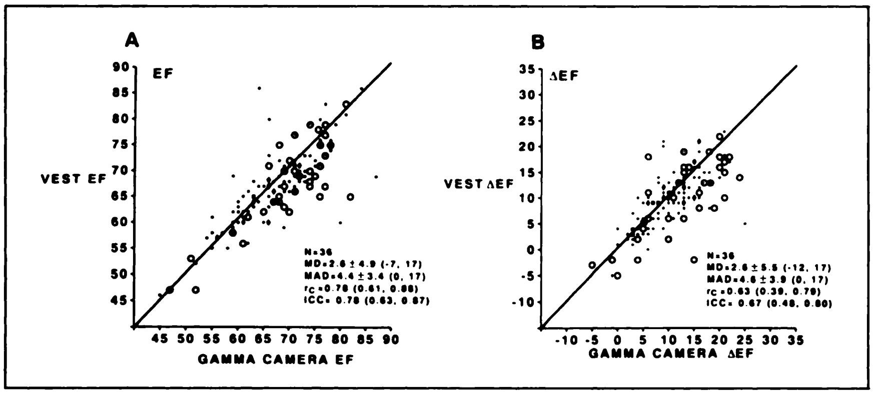

FIGURE 5. Comparison of gamma camera and VEST EF (A) and Δ EF (B). r_c = Lin concordance coefficient (95% CI). Abbreviations as previously cited. ○ = single exercise peak value, ● = single nonpeak exercise value, ● = two peak exercise values, ♦ = three nonpeak exercise values, ■ = four nonpeak exercise values, and ⊙ = one peak exercise value and one nonpeak exercise value.

potential advantage of the VEST as a clinical tool resides in its unique ability to measure EF changes continuously over time. Our results indicate that highly reproducible measurements of Δ EF are obtained during VEST monitoring while volunteers perform repetitive exercise. The measurements of Δ EF were equally reproducible using data obtained over 30 sec as compared to 2-min intervals, demonstrating the VEST's capability for dynamic serial EF monitoring. These high correlations were obtained from EF measurements during peak bicycle exercise when the most vigorous physical movement should have been present. These features suggest that VEST monitoring may be suitable for selected vigorous ambulatory physical activities involving predominantly lower extremity movement, similar to bicycle exercise.

Assessment of VEST Accuracy

Relative Reproducibility of Gamma Camera Measurements. The assessment of VEST accuracy was more problematic than assessment of reproducibility in our study due to the lack of an absolute gold standard for EF. Since we used gamma camera measurements of EF as the referent standard for accuracy in this study, we performed a series of studies designed to assess the reproducibility of EF measurements using the gamma camera. First, we assessed the intra- and interobserver variability for EF measurements between two experienced computer operators who processed the same gamma camera data twice using our patient group. Intraobserver variability was very low (ICC of 0.95 for both absolute and Δ EF). Interobserver variability was somewhat larger, but the magnitude was still relatively small (Δ EF MAD = 4.3% ± 2.6%).

The values obtained from our analysis of intra- and interobserver variability in our patient group provided us with a basis for other comparisons. First, since the assessment of intra- and interobserver variability is not independent of patient selection bias, we also assessed intraobserver variability for gamma camera EF measurements during repeat exercise in seven of the normal volunteers. The analysis was performed because the assessment of reproducibility for VEST monitoring was performed in a healthy volunteer group. Whereas the mean Δ EF differences did not vary substantially in this group compared to the patient group (Δ EF MAD = 2.2% ± 2.1% versus 4.3% ± 2.6%), the ICC was still less. This finding is expected given the more homogeneous range of EF responses in healthy volunteer populations (*15*) in comparison to diseased patient populations. Considering the same magnitude of measurement variability, a higher ICC will be derived in populations demonstrating a greater, more heterogeneous spread of data points, which represents a limitation in comparing results among studies. Thus, among the volunteer group, the ICCs were higher for VEST monitoring than for the assessment of intraobserver variability during gamma camera monitoring, indicating a greater VEST reproducibility.

We next compared the reproducibility of EF measurements in the seven volunteers who performed repeat bicycle exercise using gamma camera imaging. Whereas this comparison resulted in a relatively low ICC compared to the other gamma camera analyses, two factors suggest that caution should be applied in interpreting these results: (1) the use of a relatively small sample size and (2) the homogeneous nature of the population. In fact, EF MAD and the range of values between the first and second test measurements were not substantially different for those obtained from assessing inter- and intraobserver variability in the aforementioned analyses. There was also a practical limitation for this particular analysis, which derived from the design of our test protocol. Among the volunteers, repeat bicycle exercise was generally performed 3 to 5 hr after the injection of technetium-99m, since these volunteers were first engaged in a separate mental stress protocol (*6*). Over this time period, the number of counts in the left ventricle decreased significantly, given the physical and biologic half-life of technetium-99m. It is possible that this loss of counts could have affected the overall accuracy of EF measurements in this subgroup.

Our final analysis involved the comparison of gamma camera versus VEST measurements of absolute and Δ EF during exercise for the 36 subjects. The correlation remained relatively high for Δ EF. When the peak exercise EF responses were classified as increasing (≥ 5%), flat (<

5% change), or falling ($\geq$ 5%), a concordance between the gamma camera and VEST results was noted in 89% of the 36 subjects. Among the four outliers, only one patient demonstrated a marked disparity: EF increased by 15% during gamma camera imaging, but fell by 2% during VEST monitoring. We suspect the malpositioning of the VEST relative to the left ventricle was the most likely cause for such a discrepancy, although prospective work in more patients is needed to assess this possibility and the frequency of its occurrence. Thus, the relatively high correlation of VEST results with the gamma camera results indicate that the VEST is a relatively accurate as well as highly reproducible means of assessing changes in EF.

Comparison to Statistical Techniques Employed in Other Studies. To examine reliability and to compare two different methods for EF measurement, prior studies have used linear regression and correlation analysis (*5,16,17*). The drawbacks to both of these methods have been outlined by others (*8,18*). We chose the ICC to describe the reliability because it compares the variability between repeated measurements on the same subjects to the variability of the measurements between the subjects, independent of the ordering of the sets of scores. The Lin concordance coefficient (r_c) was chosen to compare the different methods because this index best evaluates the agreement between two readings from the same sample by measuring the variation from the line of identity.

Both the ICC and the r_c, however, are influenced by the patient population. Given similar reproducibility, populations with greater variability between subjects will have higher correlation coefficients than more homogeneous populations. Hence, it is difficult to compare these results with those of prior studies (*5,17*). Of note, Okada and coworkers demonstrated similar magnitudes of variance for control, exercise, and Δ EF values, however, they did not find a greater amount of inter- or intraobserver variability (*19*). Similarly, inclusion of EF measurements at different exercise stages on the same subject that are not statistically independent could drastically influence how heterogeneous the population appears. In some situations, multiple measurements on an individual can be handled through the analysis of variance model. However, in this study since subjects achieved different peak stages of exercise, the repeated measurements could not be easily modelled.

Assessment of the Results. The higher reproducibility of VEST measurements compared to the gamma camera is not surprising given that gamma camera EF determinations involve operator-dependent subjective determinations of background, end-diastolic, and end-systolic regions of interest. Since the determination of EF by the VEST is automatic, these subjective steps are eliminated. Of importance, patient positioning was controlled during our study, since we only assessed VEST results during upright bicycle exercise. The potential variability in VEST measurements introduced by changes in patient positioning during more spontaneous daily activity could be important and requires further investigation.

The methodologic differences between the VEST and gamma camera calculations of EF could possibly explain some of the variation between gamma camera and VEST measurements. Most notably, the VEST employs a single, fixed ventricular region of interest, compared to the variable region of interests employed for selecting end-diastole and end-systole for gamma camera measurements. This makes the VEST a less accommodating instrument in terms of patient motion against the detector field and in terms of assessment of global versus regional EF when compared to the variable region of interest technique. Second, there is probably an increase in background radioactivity during physical stress, related to an increase in pulmonary blood volume. In this study, we used a fixed background value for the VEST EF measurements (i.e., the rest value for background was used for exercise EF determinations). This approach does not take into account possible changes in background during exercise; these would be accounted for by the gamma camera approach. Theoretically, failure to account for this increase could result in an underestimation of true change in EF measurements during exercise with the VEST. Despite these concerns, no systematic difference (i.e., over- or underestimation) between VEST and gamma measurement were noted in this study.

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SELF-STUDY TEST

Gastrointestinal Nuclear Medicine

Questions are taken from the *Nuclear Medicine Self-Study Program I*, published by The Society of Nuclear Medicine

DIRECTIONS

The following items consist of a heading followed by lettered options related to that heading. Select the *one* lettered option that is best for each item. Answers may be found on page 824.

1. **A 2-month-old infant has conjugated hyperbilirubinemia. Hepatobiliary scintigraphy with ^{99m}Tc-iminodiacetic acid shows no evidence of excretion into the bowel by 24 hr. Evaluation of which *one* of the following features of the early images would be most useful in distinguishing biliary atresia from neonatal hepatitis?**

A. hepatic perfusion during the initial angiographic phase
B. the amount of renal excretion and early bladder activity
C. the delineation of intrahepatic bile ducts
D. the degree of hepatic extraction of the tracer
E. nonvisualization of the gallbladder

2. **A 65-year-old man is admitted to the emergency room because of hematochezia. His blood pressure is 90/60 mm/Hg and his heart rate is 100 bpm Figure 1 shows sequential anterior images from a ^{99m}Tc-red blood cell study. Which *one* of the following is the most likely cause for the patient's bleeding?**

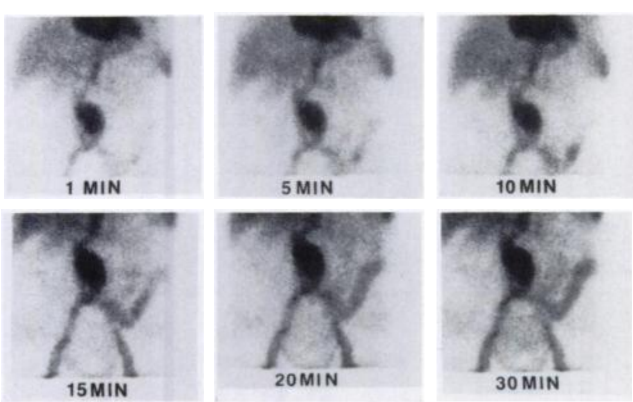

Figure 1

A. duodenal ulcer
B. aortoenteric fistula
C. diverticulum in the descending colon
D. diverticulum in the splenic flexure
E. leiomyoma of the small bowel

3. **This 48-year-old woman has nausea, vomiting, and abdominal pain 8 months following vagotomy, hemigastrectomy, and Billroth II gastrojejunostomy. There was no history of bilious vomiting. A gastric emptying study done with ^{111}In-labeled solid egg (Fig. 2A) and a concurrently performed ^{99m}Tc-disofenin hepatobiliary study (Fig. 2B) are shown. Which *one* of the following statements concerning this clinical situation and these scintigraphic results is correct?**

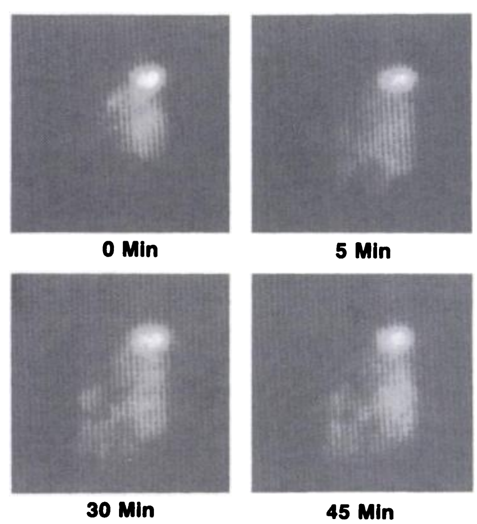

Figure 2A

(continued on p. 824)