Beat-to-beat Left Ventricular Performance Assessed from the Equilibrium Cardiac Blood Pool Using a Computerized Nuclear Probe

Harvey J. Berger, M.D., Ross A. Davies, M.D., William P. Batsford, M.D., Paul B. Hoffer, M.D., Alexander Gottschalk, M.D., and Barry L. Zaret, M.D.

with the technical assistance of Linda Pytlak, R.T.

SUMMARY The feasibility, accuracy and reproducibility of continuous beat-to-beat evaluation of left ventricular performance with a computerized nonimaging scintillation probe was assessed in 71 patients. This portable instrument has enough sensitivity to generate a real-time relative left ventricular volume curve using the labeled equilibrium blood pool without electrocardiographic gating. The probe was positioned at the left ventricular and background regions of interest using a systematic series of computerized algorithms and operator routines that were developed and standardized during the initial phase of this study. In each patient, left ventricular ejection fraction was calculated manually from the strip-chart recording in 10 consecutive sinus beats. Beat-to-beat left ventricular ejection fraction determined by the probe correlated well with first-pass studies obtained using a computerized multicrystal scintillation camera ($r = 0.92$). There was no systematic over- or underestimation, and the correlation was evident over a wide range of first-pass values (15–81%). There was excellent agreement between initial and repeat analyses ($n = 58$, $r = 0.97$) and between initial and repeat studies ($n = 48$, $r = 0.94$). The absolute variability of beat-to-beat ejection fraction measurements determined from all 710 beats was $±5.9\%$ (expressed in ejection fraction units as $±2\, SD$). This technique should provide a reliable means of addressing pathophysiologic questions that require sampling of data directly on a beat-to-beat basis.

CARDIAC BLOOD POOL IMAGING with a scintillation camera interfaced to a computer provides detailed information on global and regional left ventricular performance.$^1-^4$ However, gated equilibrium data must be acquired and averaged over several hundred cardiac cycles to obtain statistically meaningful results.$^5,^6$ Thus, the technique is not sensitive enough to detect rapidly changing physiologic events that occur on a beat-to-beat basis. An alternative radionuclide approach using the labeled equilibrium blood pool involves the use of a nonimaging scintillation probe, an instrument that is sensitive enough to generate a real-time continuous relative left ventricular volume curve without electrocardiographic gating.$^7,^8$ In this way, beat-to-beat left ventricular pump performance can be determined noninvasively based upon relative changes in ventricular volumes.

In this study, we assessed the feasibility, accuracy and reproducibility of continuous beat-to-beat evaluation of left ventricular function with a nonimaging scintillation probe. In the course of this analysis, a series of computerized probe-positioning algorithms and operator routines was validated systematically, and the overall variability of single-beat measures of global left ventricular performance was determined.

Methods

Instrumentation

The commercially available, portable, computerized nuclear probe (Nuclear Stethoscope, Bios Inc.) was used for all studies.$^9,^10$ Briefly, this unit consists of a 2-inch-diameter $\times 1\frac{3}{4}$-inch-thick thallium-activated sodium iodide crystal affixed directly to a single-bore, $3\frac{1}{2}$-inch converging collimator. The probe is mounted on a 50-inch arm that permits positioning freely over the chest and control of two separate angular degrees of freedom. The analog scintillation data and ECG are input simultaneously, converted to 12-bit binary words, and sampled at 10-msec intervals by a dedicated microprocessor (Intel 8085). This system has 6K words of programmable read only memory and 4K words of random access memory. Data are routinely displayed on a cathode ray tube with a sweep time of 12 seconds. The maximal count rate capacity of the system is 140,000 counts/sec.

A high-frequency-response, four-channel strip-chart recorder (Elmon-Schonander Mingograf 34) was interfaced directly to the analog output of the nuclear probe. This modification allows continuous display and permanent recording of the ECG and left ventricular time-activity curve (fig. 1). This means of data acquisition is critical for defining beat-to-beat events in terms of ventricular pump performance. The graphic recorder fits on the cart of the nuclear probe.
and uses a direct-writing ink-jet galvanometer with linear frequency response of 0–500 Hz. The analog data are displayed without smoothing.

The beat-to-beat left ventricular time-activity curve is also displayed in real-time at 50-msec intervals on the cathode ray tube. The peaks and valleys of the curve for each beat (rather than the ECG) are indicated as a series of dots below the time-activity curve. After digital smoothing, the average ejection fraction for individual beats displayed between two movable vertical cursors is calculated automatically by the microprocessor. However, the strip-chart recording is needed to correlate functional measurements directly with electrocardiographic events.

**Probe Positioning**

In conventional scintillation camera studies, regions of interest are selected based on visual assessment of
the actual anatomic orientation and position of the intracavitary blood pool. In contrast, positioning of the nonimaging probe requires orientation of the detector relative to the cardiac anatomy based upon a logically derived series of algorithms. Probe positions are determined empirically, based on both stroke counts (end-diastole minus end-systole) and average counts (end-diastole plus end-systole divided by two) as recorded by the probe. The left ventricular region of interest is chosen as the position with the maximal ratio of stroke counts to average counts. The background region of interest is chosen as a position immediately inferolateral to the left ventricular region of interest, where stroke counts are minimal (no periodicity) and average counts first begin to decrease. Based upon the software included with the system, the microprocessor displays a horizontal bar as a visual means of assisting the operator in optimizing the probe's position. The length of the bar, which is determined principally by relative stroke counts, changes on a beat-to-beat basis as the probe is moved over the chest (fig. 2).

To assure accurate and reproducible positioning, a series of systematic steps is required. Movement of the probe requires smooth and continuous motion to avoid abrupt artifactual changes in counts, and in this way closely resembles scanning the precordium with an ultrasound transducer. This approach was developed in this laboratory based on empirical experience in approximately 100 patients who underwent evaluation with the nuclear probe after routine radionuclide left ventricular performance studies with computerized scintillation camera techniques. In these early cases, which were studied initially to develop a standardized technique before its validation, the results of camera studies were known at the time of probe study. These patient studies were not included in the subsequent validation of the technique, which forms the basis of this report.

The systematic steps required for reproducibly determining the optimal probe positions are as follows. First, an approximate left ventricular probe position relative to the chest wall is found. With the probe in the 45° left anterior oblique position and a 10° caudal tilt (toward the feet), the left anterior chest is scanned in a series of parallel paths in the cephalad to caudal direction to identify the regions of the great vessels, left atrium and left ventricle. Then the chest is scanned in the medial to lateral direction to identify the regions of the right ventricle, interventricular septum, and left ventricle. By carefully following the length of the horizontal bar and the configuration of the actual time-activity curve, areas of maximal and minimal periodicity can be identified and related to these known anatomic structures.

Second, after the approximate left ventricular position is determined, the region of interest is defined more precisely by identifying the position corresponding to the maximal bar length (fig. 2). Once this position is determined, the obliquity in the transverse plane is adjusted in 5° increments from 30°–60° to further maximize the bar length, if possible. After the obliquity is chosen, the caudal tilt in the longitudinal

![Figure 2. Actual real-time displays of the count-rate data photographed directly from the cathode ray tube of the computerized nuclear probe. Counts are on the vertical axis. Two movable vertical cursors are shown. (A) The probe was positioned at the background (BKG) location, inferolateral to the left ventricle. Note the lack of periodicity. The length of the horizontal bar, which is shown below the horizontal axis, is controlled by the microprocessor algorithms. When the probe was positioned approximately 1 cm closer to the left ventricle, the bar was shorter than shown in this panel and at its relative minimum. (B) The probe was repositioned at the left ventricle. A real-time beat-to-beat left ventricular volume curve at 50-msec intervals is displayed above the average background level. The series of dots shown immediately above the horizontal axis represent the peaks (end-diastole) and valleys (end-systole) of the curve. The bar now is at its relative maximum. The average left ventricular ejection fraction calculated by the microprocessor for the individual beats shown between the two cursors was 59%. By first-pass radionuclide angiography, the ejection fraction was 57%. (C) A representative cardiac cycle from the same patient is shown at 10-msec intervals. Data were summed for 30 seconds, generating a curve similar to that obtained with multiple gated blood pool imaging. The ECG is shown below. The left ventricular ejection fraction calculated by the microprocessor was 60%. This mode of data acquisition can be performed in addition to the beat-to-beat analysis.](https://circ.ahajournals.org/content/73/5/135.f2)
plane is adjusted in 5° increments from 0–20° to further maximize the bar length, if possible. The optimal location, obliquity, and tilt corresponding to the left ventricular region of interest are noted.

Third, the background region of interest is determined. This is done by moving the probe, in the same obliquity and tilt as found, diagonally away from the heart, inferiorly toward the spleen and laterally toward the axilla. With this repositioning, relative stroke counts decrease until the minimal detectable level is reached. When periodicity no longer is present (noise level), the bar length becomes minimal. Beyond this location, the microprocessor is programmed to increase the bar length as the average counts begin to decrease. The probe is moved approximately 1–2 cm further away from the left ventricular region of interest until the bar length begins to increase relative to its minimum (fig. 2). This position then is chosen for the background region. For all positions, the probe is placed approximately 1 cm above the skin surface.

Data Acquisition and Display

With the probe in the previously determined background position, an average count rate is obtained for 15 seconds and stored by the microprocessor for future use. To calibrate the ventricular volume curve directly on the strip-chart recording, the output from the probe in the background position is aligned visually with one of the recording channels (fig. 3). In this way, the background activity level is represented and displayed as a continuous constant value. The probe then is moved back to the previously determined left ventricular position for data acquisition, assuring that the bar length is maximal once again. Studies should be done during relatively shallow breathing, as deep or labored breathing may result in excessive cardiac motion. The entire positioning and calibrating process takes about 10 minutes by an experienced operator.

Using this approach, the relative left ventricular volume curve recorded on the strip-chart device is displayed relative to the background activity level, thereby providing continuous recording of beat-to-beat data that can be analyzed in synchrony with the ECG. The distances from the baseline (background) to the peak and valley of the time-activity curve are proportional to end-diastolic and end-systolic counts (volume), respectively. After a study, measurements are made manually with a metric ruler to within ± 0.5-mm gradations (fig. 1). The peaks and valleys are identified visually directly from the curve.

Patient Selection

Seventy-one randomly selected adult patients referred for radionuclide assessment of left ventricular performance were included in this study. This phase of the protocol was started after the probe positioning algorithms were fully developed and standardized. Thirty-one had stable coronary artery disease, 16 valvular heart disease, seven chronic bronchitis, six cardiomyopathy and 11 miscellaneous conditions. No patient had acute myocardial infarction or unstable angina pectoris. Thirty-one were female and 40 were male. At the time of study, all were in normal sinus rhythm. Technically adequate studies could not be performed in three patients, who are excluded from analysis.

Radionuclide Methods

In all patients, left ventricular ejection fraction and regional wall motion were determined initially by first-pass radionuclide angiocardiology using a computerized multicrystal scintillation camera (Cordis-Baird System-77). Ejection fraction determined in this

**Figure 3.** Method of analysis of the beat-to-beat left ventricular volume curve. With the probe in the background (BKG) position, the output from the probe is aligned visually with one of the recording channels. The probe then is moved back to the left ventricular position. End-diastolic counts (EDC), end-systolic counts (ESC) and stroke volume counts (SVC) are measured directly from the strip-chart recording. Left ventricular ejection fraction (LVEF) is calculated by the conventional formula using these millimeter measurements.
manner has been validated against contrast angiographic measurements and has been standardized in this laboratory.\textsuperscript{15-18} This radionuclide measurement served as the standard against which probe determinations were compared. The first-pass study was obtained in the anterior position after bolus injection of approximately 20 mCi of technetium-99m pertechnetate. To allow subsequent in vivo labeling of red blood cells, 15 mg of unlabeled stannous pyrophosphate dissolved in 3 ml of normal saline were injected intravenously 15 minutes before the first-pass study. Probe studies were performed within 30 minutes of the first-pass study, but without any knowledge of the clinical history or the results of the scintillation camera data. This comparative radionuclide approach already has been applied to the assessment of first-pass and gated equilibrium blood pool studies.\textsuperscript{5,6} All first-pass studies were analyzed independently by a different operator.

**Initial Probe Study**

In all patients, 10 consecutive beats were analyzed manually from the strip-chart recording by a single observer (fig. 1). For each of the beats, measurements of relative end-diastolic and stroke counts (volumes), as well as ejection fraction were made. In addition, average left ventricular ejection fraction was determined automatically by the microprocessor from 10 consecutive beats displayed simultaneously on the cathode ray tube (fig. 2).

**Repeat Probe Analysis**

In 58 randomly selected studies, the strip-chart recording was analyzed a second time without knowledge of the original results. The two analyses were separated by at least 6 months. In 38 studies, the repeat analysis was performed by the same observer as in the original analysis, and in 20 studies, the repeat analysis was performed by a second observer.

**Repeat Probe Studies**

In 48 randomly selected patients, the entire probe study was repeated approximately 30 minutes after the original study. This included redefining the background and left ventricular positions, as well as recalibrating the strip-chart recording for background. No marks were made on the chest after the first study. In 28 patients, the repeat study was performed by the same operator as the original, and in 20 studies, the repeat study was performed by a second experienced operator. In the latter case, the second operator was not present when the original study was undertaken. All strip-chart recordings were analyzed by a single observer without knowledge of the original results.

**Statistical analysis**

Group data are presented as the mean ± SEM. Comparisons within individual patients were made by the paired $t$ test. Regression equations and correlation coefficients were determined using standard equations.\textsuperscript{19, 20} In the manual analysis of each probe study, the mean and standard deviation of the 10 consecutive beats were determined for stroke counts (mm), end-diastolic counts (mm) and left ventricular ejection fraction (stroke counts $\div$ end-diastolic counts $\times$ 100). The mean value for ejection fraction in the 10 beats was used for comparisons with first-pass studies, microprocessor-based calculations, and repeat probe studies and analyses. In addition, the ejection fraction from the first of the 10 beats was compared individually with first-pass results.

The variability of manually determined beat-to-beat measurement of ejection fraction and relative volumes must be characterized differently, because values are expressed differently; that is, as an absolute percent for ejection fraction and as a relative percent for volumes (mm). The pooled standard deviation of ejection fraction determinations and the pooled coefficient of variation of relative volumes were determined from the 710 beats analyzed in the 71 patients. For this study, the overall variability of these analog measurements was defined as twice these pooled estimates, accounting for approximately 95\% of the expected variation. The $F$ test was used to compare variabilities in different subgroups.\textsuperscript{19, 20}

Using the theory of error propagation, an estimation of the overall statistical uncertainty of ejection fraction can be obtained from the independent counting errors in the end-diastolic and end-systolic count rates, as well as the background activity level.\textsuperscript{21, 22} In the present analysis, count rates were obtained from the probe's microprocessor. The counting error in background was based upon the assumption that background data were recorded at the same framing interval as ventricular data (50 msec). However, background was acquired over 15 seconds and then normalized to a 50-msec time interval and expressed as a constant value. The statistical uncertainty of the total background counts (approximately 1 million) derived in this manner is substantially less than that derived when data are acquired for only 50 msec. Therefore, the overall statistical uncertainty obtained represents the maximal value, which is based upon an overestimation of the error in background.

For this study, the uncertainty is expressed as twice the standard deviation (in ejection fraction units) for a given ejection fraction value.

**Results**

**Comparison with First-pass Studies**

Left ventricular ejection fraction ranged from 15–81\% by first-pass radionuclide angiocardiography. Forty-six of 71 patients had abnormal (\(< 55\%)\) ejection fraction, and 23 had discrete regional wall motion abnormalities. Average beat-to-beat ejection fraction determined by the probe's microprocessor correlated well with first-pass studies ($r = 0.93$) and was not significantly different (53 ± 3\% vs 51 ± 3\%, NS).
Similarly, mean beat-to-beat ejection fraction determined manually from the strip-chart recorder correlated well with first-pass studies \( (r = 0.92) \) (fig. 4) and microprocessor-based measurements \( (r = 0.95) \). Mean beat-to-beat left ventricular ejection fraction averaged \( 52 \pm 3\% \) and was not significantly different from either first-pass or microprocessor-based measurements (NS).

The correlation between manually derived beat-to-beat ejection fraction and first-pass studies was evident over a wide range of values, including patients with normal ejection fraction \( (r = 0.86) \), abnormal ejection fraction \( (r = 0.94) \), and regional wall motion abnormalities \( (r = 0.92) \). The correlations were similar in males \( (r = 0.93) \) and females \( (r = 0.89) \), as well as in patients with coronary artery disease \( (r = 0.92) \), chronic bronchitis \( (r = 0.89) \) and valvular heart disease \( (r = 0.92) \). The relationship between first-pass and beat-to-beat probe studies clustered around the line of identity without systematic over- or underestimation (fig. 4).

Furthermore, when the first of the 10 consecutive beats from the strip-chart recording was analyzed individually, there still was a good correlation with first-pass values \( (r = 0.86) \). This was evident in all the patient subgroups \( (r = > 0.82 \) in all cases). Overall, there was no difference in single-beat probe ejection fraction and first-pass data \( (54 \pm 4\% \) vs \( 51 \pm 3\%, \) NS).

**Repeat Analysis**

In the 58 studies that were reanalyzed manually, there was excellent agreement between initial and repeat analyses \( (r = 0.97) \) (fig. 5). In addition, there was no significant difference in their mean values \( (53 \pm 2\% \) vs \( 53 \pm 3\%, \) respectively, NS). Similar correlations were evident when the repeat analysis was performed by the same observer \( (r = 0.98) \) and by the second observer \( (r = 0.95) \).

**Repeat Study**

In the 48 patients who underwent repeat study, there also was excellent agreement between initial and repeat probe determinations \( (r = 0.94) \) (fig. 6). There was no significant difference in their mean values \( (51 \pm 2\% \) vs \( 52 \pm 3\%, \) NS). Similar correlations were evident when the repeat study was performed by the same observer \( (r = 0.95) \) and by the second observer \( (r = 0.94) \). The mean absolute interstudy difference was \( 4.1\% \).

**Variability**

The absolute variability of beat-to-beat ejection fraction measurements was \( \pm 5.9\% \) (in ejection fraction units) and was not significantly different in patients with normal and abnormal ejection fractions \( (6.0\% \) vs \( 5.9\%, \) respectively, NS). The variabilities of relative stroke counts (volume) and end-diastolic counts (volume) were 12.6\% and 9.3\%, respectively. Both variabilities were comparable in patients with normal and abnormal ejection fractions (NS). On a beat-to-beat basis, relative stroke volume was proportional to relative end-diastolic volume \( (r = 0.91) \).

**Technical Considerations**

The end-diastolic count rate for a single beat before background correction ranged from 2450–6220.
counts/50 msec and averaged 4930 counts/50 msec (fig. 2). Background usually comprised approximately 60–70% of end-diastolic counts. Using these mean values, an ejection fraction of 50% would have a maximal statistical uncertainty (±2 standard deviations in ejection fraction units) of approximately ±10%. Assuming no error in background, the statistical uncertainty would be ±5%.

Discussion

This study demonstrates that global left ventricular performance can be assessed noninvasively on a beat-to-beat basis in a standardized manner from the equilibrium cardiac blood pool using the computerized nuclear probe. This instrument originally was developed by Wagner et al., who demonstrated its clinical value.4–12 The major assumptions of this nonimaging approach are that changes in externally detected radioactive counts reflect proportional changes in left ventricular volumes and that the left ventricular region of interest can be isolated from the surrounding structures. Although this technique allows determination of left ventricular ejection fraction and is a sensitive measurement of systolic global pump performance and relative left ventricular volumes, it does not provide information on regional function. This approach should not be viewed in competition with the conventional scintillation camera-computer techniques, but rather as a complementary technique to be used specifically to address different pathophysiologic questions that require sampling of data directly on a beat-to-beat basis.

Beat-to-beat left ventricular ejection fraction determined with the probe agrees closely with data derived using conventional scintillation camera techniques. This relationship is linear over a wide range of ejection fractions without systematic under- or overestimation. When standardized carefully, the positioning and analytical methods appear to be highly reproducible (fig. 5 and 6). Although probe positioning requires careful use of a systematic scheme, the process is relatively easy to perform after experience is gained with the system. Neither echocardiography nor fluoroscopy is needed for accurate positioning. The variability of single-beat measurements obtained from unprocessed analog data is acceptably low and comparable to previously determined estimates of variability for first-pass radionuclide angiography and gated cardiac blood pool imaging.8, 16 Changes in ejection fraction or relative volumes in single beats that are greater than these measured estimates of variability should represent real physiologic changes. The technique appears to be sensitive enough to allow detection of hemodynamic alterations induced by cardiac dysrhythmias on a beat-to-beat basis (fig. 7).

Although the technique we describe is tedious, the data it provides should permit physiologic insights that cannot be obtained using conventional radionuclide methods. Issues dealing with the hemodynamic consequences of cardiac arrhythmias, such as the effects of the site of origin of ectopic activity and of cycle length on induced or spontaneous ectopy, the effects of single ectopic beats vs runs of tachycardia, etc., could be addressed directly with this technique. Future modifications of the system will permit automated beat-to-beat analysis using either the probe’s microprocessor or an interfaced larger computer. This approach will permit digital filtering and smoothing of the raw data, thereby reducing the statistical uncertainty, as well as allowing determination of other systolic and diastolic measures of global left ventricular performance. Finally, the introduction of a pressure signal into the system should allow assessment of pressure-volume relationships on a beat-to-beat basis. However, it must be noted that this nonimaging approach is dependent upon appropriate positioning of the probe at the left ventricular and background regions and that changes in patient positioning relative to the probe, respiratory status, and other physiologic events may affect the accuracy of these data. Further studies in both animal models and man will be needed to validate the measurements in various situations.

Although other noninvasive methods have been applied to beat-to-beat evaluation of left ventricular performance, each approach has specific limitations that do not apply to the radionuclide technique described in this study. For example, M-mode echocardiography is not well suited to the study of patients with regional left ventricular dysfunction and ischemic heart disease.23, 24 Cinéfluoroscopic analysis of myocardial markers is limited to patients who have undergone thoracotomy for placement of the markers.28 Both of these techniques require geometric assumptions concerning the shape of the left ventricle.
to obtain ventricular volume measurements. In addition, systolic time intervals only provide indirect measurements of left ventricular function, and their validity has been questioned.26, 27

The probe technique uses a constant background correction. In stable physiologic states, this should introduce little, if any, error in assessing beat-to-beat function, but under rapidly changing states, such as ischemia and/or ectopy, the background also could be altered independently. However, this appears unlikely, because the background correction used predominantly represents scattered radiation from the spleen, left ventricle and descending aorta. The pulmonary blood volume, which might be expected to change based upon previous camera studies,28 contributes little to the actual background chosen with the probe. Furthermore, when serial studies are performed, the background level on the strip-chart recorder must be redefined approximately every 30 minutes to correct for physical decay of the radioisotope and potential changes in the distribution of background activity.

These data demonstrate that the probe provides accurate assessment of left ventricular ejection fraction. Nevertheless, several potential sources of error should be mentioned. First, the collimator is designed to provide appropriate isosensitivity contours and a field of view limited to the left ventricle. However, if the heart is small and the field of view is relatively too large, both end-diastolic and end-systolic counts would be overestimated. The effects would be greatest on end-systolic counts, especially in the normal range, leading to underestimation of the true ejection fraction. This also may occur in patients with an enlarged right ventricle or left atrium, which could make isolation of the left ventricle from surrounding cardiac structures more difficult. Similarly, as the distance between the collimator and the source of activity increases, the isosensitivity response contours widen because of collimator geometry and scatter. This may make the collimator's field of view too broad in some female, obese or emphysematous patients. If the left ventricle is enlarged and the field of view is relatively too small, end-diastolic counts predominantly would be underestimated, resulting in underestimation of the true ejection fraction.29

Second, by nature of the probe's design, a fixed region of interest is used for data acquisition and analysis. Most computer programs for gated cardiac blood pool imaging use a variable region of interest,5, 6 although fixed regions have been used effectively.4, 7, 8 A fixed region of interest corresponding approximately to end-diastole predominantly will overestimate end-systolic counts, which also would underestimate the true ejection fraction, especially in the normal range.29

Third, a constant position is used for the probe relative to the heart. This positioning does not take into account cardiac motion due to long-axis rotation and to respiratory motion. Particularly in beat-to-beat analysis, when data are not averaged over several respiratory cycles, shift of the left ventricle partially out of the field of view during inspiration might result in inclusion of noncardiac structures in the field of view, resulting in underestimation of the true ejection fraction.

![Figure 7](http://circ.ahajournals.org/)
fraction. However, respiratory fluctuations can be detected easily during the study by observing the position of the volume curve relative to the baseline, and studies usually are performed during relatively shallow breathing.

Fourth, technical considerations relating to detector efficiency may affect the results. The count-rate response of the probe is assumed to be directly proportional to chamber volume. Previous studies with a similar cylindrically collimated probe showed a relatively linear response over a volume range encompassing most clinically observed values. However, nonlinearity due to self-attenuation may be significant in markedly enlarged ventricles and would underestimate the true ejection fraction. 13, 29

Fifth, in patients with discrete left ventricular dyssynergy, the probe would tend to overestimate the true ejection fraction by being positioned over a relatively well-contracting region, excluding the area of dyssynergy. This theoretical limitation would apply mostly to inferior dyssynergic regions, rather than the more dyssynergic anterolateral regions. In the latter case, the dyssynergic region would be en face to the collimator and thus not excluded from the field of view when the probe is in the left anterior oblique position. Difficulty in determining ejection fraction in patients with dyssynergic regions applies not only to probe techniques but also to conventional camera studies. Furthermore, in the present report, the correlation between probe and camera ejection fractions was comparable in patients with and without regional wall motion abnormalities.

Except for the last example, these sources of error would tend to underestimate the true ejection fraction, albeit to a variable degree in different patients. 22, 29 However, this study clearly demonstrates that the ejection fraction can be assessed accurately despite these potential errors. The background correction shifts the ejection fraction upward, in agreement with determinations made with conventional techniques. Determination of background also is a potential source of error, which may vary in individual patients based upon the distribution of background activity. 13 Although not infallible, the algorithms described offer a systematic approach of dealing with these issues. The use of a background correction is not unique to the probe system. All radionuclide left ventricular performance studies using scintillation cameras require empirical and somewhat arbitrary background corrections that take into account scattered radiation from overlaying and adjacent structures. 8, 4, 7, 10, 18 As shown in this and other studies, background also can be determined reproducibly and systematically with probe systems, allowing accurate assessment of left ventricular performance based on count rate changes. 11, 12, 14

References


diol 28: 575, 1971


22. Williams DL, Hamilton GW: The effect of errors in determining left ventricular ejection fraction from radionuclide counting data. In Nuclear Cardiology: Selected Computer Aspects,
The Mechanism of Abnormal Septal Motion in Atrial Septal Defect: Pre- and Postoperative Study by Radionuclide Ventriculography in Adults


SUMMARY The mechanism of abnormal interventricular septal wall (IVS) motion in atrial septal defect (ASD) was studied by radionuclide cineventriculography before and within 2 weeks of ASD closure in 11 adult patients. Pre- and postoperative right ventricular/left ventricular volume ratio (RV/LV volume), LV peak filling rate (PFR) and LV ejection fraction (EF) were measured and compared with measurements in 13 normal adults.

In normal subjects the configuration of the left ventricle was ovoid in diastole and the IVS curvature was convex toward the right ventricle. In all 11 ASD patients increased RV volume caused the IVS either to flatten during diastole or reverse its normal direction of curvature, becoming convex toward the left ventricle and resulting in a crescentic LV configuration. In early systole the IVS bulged anteriorly as the left ventricle reassumed its normal ovoid configuration and thereafter contracted normally. Postoperatively, RV volume decreased and both diastolic LV configuration and diastolic IVS curvature returned to normal in nine of the 11 patients. Postoperatively, mean RV/LV volume (± SD) decreased (3.6 ± 0.5:1 preop vs 2.1 ± 0.8:1 postop, p < 0.001; normal subjects 1.3 ± 0.1:1). PFR increased (2.13 ± 0.57/sec vs 3.16 ± 1.19/sec, p < 0.01; normal subjects 2.92 ± 1.28/sec) and EF was unchanged (0.62 ± 0.12 vs 0.69 ± 0.09; NS; normal subjects 0.66 ± 0.08). In three older patients a low LV EF returned to normal postoperatively.

Systolic anterior IVS motion in ASD is caused by an initial abnormal curvature of the IVS during diastole to accommodate increased RV volume, and the IVS curvature returns to normal when this is relieved. The increased RV/LV volume ratio decreases and indexes of LV filling and ejection may improve early after ASD closure in adults.

ALTHOUGH paradoxical systolic anterior motion of the interventricular septal wall (IVS) is an echocardiographic finding in atrial septal defect (ASD), its cause is uncertain. It has been reported to be caused by exaggerated systolic anterior motion of the entire heart, posterior displacement of the septum from right ventricular (RV) overload or anterior septal displacement at the onset of systole. Weyman et al., using short-axis cross-sectional echocardiography, suggested the abnormal septal motion was due to a change in the diastolic shape of the left ventricle caused by RV volume overload. Contrast left ventriculography in the left anterior oblique (LAO) projection has not shown these changes, but foreshortening of the left ventricular (LV) cavity is imaged in this view, and changes in IVS and LV shape may be obscured.

Equilibrium-gated radionuclide cineventriculography using a slant-hole collimator allows sufficient...
Beat-to-beat left ventricular performance assessed from the equilibrium cardiac blood pool using a computerized nuclear probe.
H J Berger, R A Davies, W P Batsford, P B Hoffer, A Gottschalk and B L Zaret

Circulation. 1981;63:133-142
doi: 10.1161/01.CIR.63.1.133

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1981 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/63/1/133

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org/subscriptions/