Left Ventricular Performance Assessed by Radionuclide Angiocardiography and Echocardiography in Patients with Previous Myocardial Infarction

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SUMMARY
In 61 patients (77 studies) who had a transmural myocardial infarction, we compared the left ventricular ejection fraction by echocardiography with the ejection fraction determined by a computerized radioisotope technique that makes no assumptions regarding left ventricular geometry. In 31 studies of 26 patients with normal left ventricular wall motion by videotracking and normal left heart size, ejection fraction averaged 0.57 ± 0.09 (SD) by ultrasound and 0.62 ± 0.10 by the isotope method. Measurements of ejection fraction by both techniques correlated well (r = 0.86) and there was complete separation between patients with normal and reduced ejection fraction. In 46 studies of 35 patients in whom left ventricular wall motion abnormalities were recorded by videotracking, ejection fraction by the isotope method averaged 0.46 ± 0.08, while average echo ejection fraction was 0.62 ± 0.12. The correlation between the ultrasound and isotope methods in these 46 studies was poor (r = 0.33) and in 28 studies measurement of the ejection fraction by the two techniques was discordant. In 26 of the 27 studies where there was a reduced ejection fraction by the isotope method and a normal ejection fraction by echo, the dyssynergy involved the anterolateral left ventricular wall. These data indicate that echocardiographic measurements frequently overestimate left ventricular performance in patients with previous myocardial infarction associated with anterolateral wall motion disorders.

The left ventricular ejection fraction and velocity of internal diameter shortening are useful measurements of left ventricular performance.1-4 Echocardiography is a noninvasive method for measuring left ventricular dimensions, volume, ejection fraction, and the mean rate of internal diameter shortening. Furthermore, these measurements of left ventricular performance correlate well with those derived from biplane cineangiography in normal subjects and patients with left ventricular disease.5-8 Usually, the quantitative assessment of left ventricular performance by ultrasound is performed by measuring a single chord in the transverse plane of the left ventricular chamber. Measurements of left ventricular volume are based on a theoretical elliptical model and the assessment of ejection phase indices is based on the assumption that the recorded segmental function is representative of the entire left ventricle. However, regional left ventricular wall motion abnormalities occur in most patients with acute transmural myocardial infarction and persist in the majority of postinfarction patients.7 Furthermore, the reduction in left ventricular ejection fraction after myocardial infarction correlates with the extent and severity of segmental wall motion abnormalities.8 The presence of abnormal wall motion with or without left ventricular dilatation distorts left ventricular geometry and may lead to an erroneous estimation of left ventricular volumes when data are derived from the recording of a single standardized echo beam. Therefore, we examined the influence of left ventricular wall motion abnormalities and left ventricular enlargement on the echocardiographic measurement of the left ventricular ejection fraction in patients with myocardial infarction. We compared the echo results with the radioisotope ejection fraction utilizing a computerized isotope technique that makes no assumptions with regard to left ventricular geometry.

Subjects and Methods
Sixty-one patients, 51 men and 10 women, with well documented transmural myocardial infarction were studied.
on one or more occasions (77 total studies). The diagnosis of myocardial infarction was based on at least two of the following criteria: 1) a history of typical prolonged chest pain, 2) electrocardiographic changes indicative of acute myocardial injury with the subsequent evolution of a typical transmural infarction pattern and 3) characteristic elevations of serum enzymes (CPK, GOT and/or LDH). Their average age was 59.2 years (range 38 to 82). In 14 patients studies were performed one to 15 days (average 4.5 days) after acute myocardial infarction and in 47 patients one to 53 months (average 20.2 months) after infarction. Serial studies were obtained on two or more occasions three days to 11 months after infarction in 13 patients whose left heart size and/or left ventricular wall motion changed after myocardial infarction.

Wall motion videotracking was performed as previously described employing a commercially available device (Biotronex Heart Motion Videotracker). Utilizing a 23 cm image intensifier, the fluoroscopic cardiac silhouette was displayed on a Plumbicon television system and either recorded on videotape for later analysis or tracked directly during the fluoroscopic study. The analog videotracking signal was recorded on a Honeywell Visicorder photographic system for subsequent analysis. Recordings were made of five sites between the high and low transmural pattern and 3) infarction. The left ventricular wall motion changed after time.

The left ventricular endocardium and consistent localization of the ultrasound beam, echoes from the anterior mitral valve leaflet and chordal structures were included in the echocardiographic tracing. In each case, end-diastolic and end-systolic volumes were calculated by the cube method of Rombo and associates using the average of three beats. Ejection fraction was calculated as the ratio of stroke volume to end-diastolic volume. An electrocardiographic lead II, and an indirect carotid arterial pulse tracing were recorded simultaneously with the echocardiogram on the multichannel recorder. The mean rate of internal diameter shortening (Vcf) was calculated using previously described methods. A recently described radioisotope method for measuring left ventricular ejection fraction was employed. By this method, ejection fraction is derived from instantaneous count rates corresponding to the changes in left ventricular volume at end-systole and end-diastole, and no assumptions are made with respect to left ventricular geometry (fig. 2). $^{99m}$Tc(10 to 14 mCi) sputum pertechnetate, dissolved in one ml of 0.9% NaCl) was injected into an antecubital or external jugular vein. Precordial activity was recorded during the first circulation through the heart with a gamma scintillation camera (Searle Pho-Gamma HP) equipped with a medium energy 4000 parallel hole collimator in a 30° right anterior oblique position and stored in real time on magnetic tape (Searle Data Storage/Accessory). A small dedicated computer (Med II, General Electric Company, Milwaukee, Wisconsin) was utilized to generate time-activity curves from the left ventricular blood pool. Ejection fraction was computed from the cyclic fluctuations of the left ventricular time-activity curve by dividing the difference between count rates at end-diastole and at end-systole by the count rate at end-diastole. In each study, the counts collected in the background region of interest were multiplied by the ratio of the number of matrix points in the left ventricular region of interest to the number of matrix points in the background region of interest, usually four or five, and subtracted from the left ventricular time-activity curve.

The external left heart dimension was used as an index of left ventricular size. It was measured as the widest distance from anterior midline markers to the left heart border on a calibrated supine frontal chest X-ray exposed precisely at end-diastole by means of an electrocardiographic gating device after a measured inspiration of 1000 ml above functional residual capacity. It has previously been shown that the external left heart dimension correlates well with cineangiographic measurements of left ventricular size.

The ultrasound method for determining left ventricular dimensions has been described previously in detail. A commercially available ultrasonoscope (Picker Echoview 11) was employed utilizing a 2.25 MHz, 1.25 cm transducer focused at 7.5 cm, or a 1.6 MHz, 1.9 cm transducer focused at 10 cm, both with a repetition rate of 1000 impulses per second. The output of the ultrasonoscope was displayed and recorded on a Honeywell Visicorder Oscillograph Model 1856. The standard technique of examining the structures traversed by a single beam through the body of the left ventricle was followed. Ultrasound reflections were obtained anteriorly from the interventricular septal endocardium, and posteriorly from the left ventricular posterior wall endocardial surface (fig. 1). To assure accurate definition of the left ventricular endocardium and consistent localization of the ultrasound beam, echoes from the anterior mitral valve leaflet and chordal structures were included in the echocardiographic tracing. In each case, end-diastolic and end-systolic volumes were calculated by the cube method of Rombo and associates and by the regression formula of Fortuin and coworkers, using the average of three beats. Ejection fraction was calculated as the ratio of stroke volume to end-diastolic volume. An electrocardiographic lead II, and an indirect carotid arterial pulse tracing were recorded simultaneously with the echocardiogram on the multichannel recorder. The mean rate of internal diameter shortening (Vcf) was calculated using previously described methods. A recently described radioisotope method for measuring left ventricular ejection fraction was employed. By this method, ejection fraction is derived from instantaneous count rates corresponding to the changes in left ventricular volume at end-systole and end-diastole, and no assumptions are made with respect to left ventricular geometry (fig. 2). $^{99m}$Tc(10 to 14 mCi) sputum pertechnetate, dissolved in one ml of 0.9% NaCl) was injected into an antecubital or external jugular vein. Precordial activity was recorded during the first circulation through the heart with a gamma scintillation camera (Searle Pho-Gamma HP) equipped with a medium energy 4000 parallel hole collimator in a 30° right anterior oblique position and stored in real time on magnetic tape (Searle Data Storage/Accessory). A small dedicated computer (Med II, General Electric Company, Milwaukee, Wisconsin) was utilized to generate time-activity curves from the left ventricular blood pool. Ejection fraction was computed from the cyclic fluctuations of the left ventricular time-activity curve by dividing the difference between count rates at end-diastole and at end-systole by the count rate at end-diastole. In each study, the counts collected in the background region of interest were multiplied by the ratio of the number of matrix points in the left ventricular region of interest to the number of matrix points in the background region of interest, usually four or five, and subtracted from the left ventricular time-activity curve.

**Figure 1**

Echocardiogram showing the left ventricular endocardial surface of the interventricular septum (IVS) and the left ventricular posterior wall endocardium (END). Inclusion of the posterior chordae (PC) and anterior mitral valve leaflet insure accurate definition of the left ventricular endocardium and consistent localization of the ultrasound beam. The simultaneous electrocardiogram (ECG), carotid arterial pulse tracing (CPT) and time-distance markers are incorporated in the display. The left ventricular internal end-diastolic dimension (LVIDd) between endocardial surfaces was measured along the vertical line through the peak of the QRS complex. The left ventricular internal end-systolic dimension (LVIDs) is defined as the smallest distance separating the endocardial surfaces of the septum and posterior wall. EPI = epicardium; LVET = left ventricular ejection time.
Moreover, in view of the relatively low count rates, the statistical reliability of this technique was improved by employing a standard sine-wave analysis, thus including all curve points into the calculation of the left ventricular ejection fraction.\textsuperscript{18}

Other investigators have shown previously that the ejection fraction determined by similar radioisotope techniques correlates well with the ejection fraction measured by single plane cineangiography.\textsuperscript{17, 18} More recently, we reported an excellent correlation between the ejection fraction by the radioisotope technique used in this study and the ejection fraction measured by biplane left ventricular cineangiography in 20 patients, 14 of whom had coronary artery disease and nine of whom had major wall motion abnormalities.\textsuperscript{18}

Ultrasound examinations and isotope studies were performed within one hour on the same day in each patient. All patients were in sinus rhythm and none had angina pectoris during the procedure. No medications were taken between the two procedures.

Data were analyzed using standard statistical methods with the aid of a Sigma III computer.

**Results**

Seventy-seven studies were performed in 61 patients. The average left ventricular ejection fraction was $0.51 \pm 0.10$ (SD) by the radioisotope method and was significantly higher by ultrasound ($0.63 \pm 0.11$, $P < 0.001$). For the entire patient group, there was a poor correlation between the isotope and echo measurements of ejection fraction ($r = 0.43$).

In the 31 studies in 26 patients with normal left ventricular wall motion by videotracking and normal left heart size, the ejection fraction by the radioisotope method averaged $0.57 \pm 0.09$ as compared to an echocardiographic ejection fraction (cube method) of $0.62 \pm 0.10$ (Fig. 3). For this group of patients, there was a good correlation between the isotope and echo measurements of ejection fraction ($r = 0.86$).

However, the correlation between the two methods was slightly reduced when the echo ejection fraction was calculated using the regression equation of Forrester and coworkers ($r = 0.76$). The two methods for determining ejection fraction were concordant, i.e., six patients had an abnormal ejection fraction ($< 0.52$) and the remaining 25 patients had a normal ejection fraction by both methods.

In the 46 studies in 35 patients with abnormal left
ventricular wall motion by videotracking, the ejection fraction by the isotope method averaged 0.46 ± 0.08, while ejection fraction by ultrasound averaged 0.62 ± 0.12 (P < 0.001) (fig. 4). In 28 of the 46 studies measurements of the ejection fraction by the two methods were discordant. Thus, in 27 studies the ejection fraction was normal (> 0.52) by the echocardiographic technique and reduced by the radioisotope method, while in one patient the ejection fraction was reduced by echo and normal by the isotope method. For these postinfarction patients with abnormal wall motion, 16 of whom (35%) also had cardiomegaly (left heart dimension > 52 mm/m² BSA), there was a poor correlation between the isotope and echo measurements of the ejection fraction (r = 0.33). Substituting the volume formula of Fortuin and associates for the echo measurement of ejection fraction did not improve the correlation between the two methods (r = 0.34). In the 16 patients with cardiomegaly, there was also a poor correlation between the measurements of the ejection fraction by the two methods (r = 0.39), regardless of which echo formula was used for calculating left ventricular volumes.

Thirty-eight of 46 (83%) wall motion videotracking studies in the 35 patients with left ventricular dyssynergy demonstrated involvement of the anterolateral left ventricular surface and an associated apical abnormality was present in 30 (79%) of these studies. An isolated abnormality of the lateral left ventricular wall occurred in only three patients and of the anterior left ventricular wall in only two patients. Four of the five patients with posterior wall motion disorders also had involvement of the lateral or apical surface of the left ventricle. Twenty-seven of the 46 studies (59%) where wall motion abnormalities were present demonstrated a reduced ejection fraction by the isotope method and a normal ejection fraction by the echo method (fig. 3). In 23 of these 27 studies the wall motion abnormality involved the anterolateral left ventricular surface, in two the lateral, in one the anterior, and in another the apical surface. Only two of the patients with anterolateral dyssynergy had an associated posterior wall motion abnormality.

The mean rate of internal diameter shortening (mean Vcf) averaged 1.02 ± 0.04 circ/sec for the 30 studies in patients with normal wall motion and 0.98 ± 0.04 circ/sec for the 46 studies in patients with abnormal wall motion. Thirteen of the 46 studies (28%) in patients with wall motion disorders demonstrated a normal mean Vcf by ultrasound (> 1.05 circ/sec) but a reduced ejection fraction by the isotope technique. In all 13 patients the wall motion abnormality involved the anterolateral or lateral surface, extending only in two to the posterior wall.

Figure 5 illustrates serial left ventricular echocardiograms in a patient with an anterolateral myocardial infarction who had dyskinesis of the low anterior, apical and lateral left ventricular surfaces. During the first study, the patient was in cardiogenic shock, and the cardiac index was 1.4 L/min/m² by the thermodilution technique when the ejection fraction by the isotope method was 0.36. However, the simultaneous echocardiographic measurement of the ejection fraction was normal (0.72) and the tracing showed an exaggerated septal excursion of 1.1 cm and a normal systolic posterior wall movement of 1.1 cm. There was no systolic murmur and right heart catheterization did not indicate either mitral regurgitation or a ventricular septal defect. During the second study two months later the patient was no longer in congestive heart failure and the dyskinesis of the anterolateral left ventricular wall had improved. The isotope ejection fraction had increased to 0.58, but the echo method again overestimated the ejection fraction (0.80). The ultrasound recording again showed an exaggerated septal motion of 1.2 cm suggesting a localized reduction in myocardial performance at a site not traversed by the single echo beam.

**Discussion**

Assumptions Underlying Ultrasound Methods

In the standard echocardiographic technique for determining left ventricular volumes and ejection fraction, the left ventricular end-diastolic and end-
systolic distances between opposing endocardial surfaces of the interventricular septum and left ventricular posterior wall immediately inferior to the mitral valve echo are measured. The usefulness of these indices of ventricular performance has been demonstrated in selected groups of patients. The cube method for determining left ventricular volumes is based on the following assumptions: first, that the motion of the two opposed loci traversed by a single standardized echo beam is representative of the motion and function of the entire left ventricular chamber; second, that the chord measured by the ultrasound beam is a true minor axis; and third, that the longitudinal axis of the cavity is twice the minor axis. In the chamber with disordered wall motion the first two assumptions may not be valid since the location and degree of segmental wall motion abnormalities vary and the area traversed by the single chord may not represent the performance of the remainder of the left ventricle. The third assumption applies where left ventricular volume is normal. However, when left ventricular dilatation results in a more spherical chamber, the ratio of the long to the short axis will decrease and lead to progressive overestimation of volume. For determination of left ventricular volumes in patients with cardiomegaly, regression equations correcting for this discrepancy are available.

Influence of Abnormal Wall Motion on Ultrasound Measurements

Utilizing wall motion videotracking, we have shown previously that major wall motion abnormalities can be demonstrated in 86% of patients with acute myocardial infarction. Dyssynergy after myocardial infarction is most commonly located at the anterior, lateral, anterolateral or apical surfaces of the left ventricle. External videotracking often does not detect wall motion disorders limited to the septal or diaphragmatic portion of the left ventricular surface. However, wall motion disorders involving the posteroinferior left ventricular surface can be detected in the majority of patients since such abnormalities extend to the left ventricular apex in 88% of patients with inferior myocardial infarction. The standard ultrasonic beam passes through the superior portion of the interventricular septum and the basal portion of the posterior left ventricular wall. Since reduced systolic inward movement or dyskinesis of one of the ventricular surfaces often results in compensatory increased excursion of the opposing surface, the echo measurement may overestimate the ejection fraction, particularly when either septal or posterior wall motion is unchanged or enhanced.

Utilizing M-mode scanning of the left ventricle between the aortic root and the posterior papillary muscle, Feigenbaum and associates have demonstrated that the echocardiogram can be used to detect left ventricular asynergy in patients with coronary artery disease. However, in the current investigation where a standard single beam echo was employed, only 15 of the 46 studies (33%) in patients with abnormal left ventricular wall motion determined by videotracking exhibited abnormal wall motion by ultrasound. In these 15 studies the ejection fraction by echo did not correlate better with the isotope ejection fraction.
(\(r = 0.39\)) as compared to the total group of studies in patients with wall motion disorders. This correlation was similar when patients with exaggerated motion of either wall were excluded, although the echocardiographic overestimation of ejection fraction was considerably less (11 %) as compared to the average overestimate of 35 % in the total group of patients with wall motion abnormalities.

Thus, it appears that even when areas of asynery are included in the standard echocardiographic recording, over-all left ventricular performance may not be assessed accurately. This is so because of the variable extent, severity and location of segmental wall motion abnormalities in postinfarction patients. Furthermore, the interventricular septum or the posterior left ventricular wall are rarely the solitary site of a wall motion abnormality after myocardial infarction. In the present investigation, only one of the 31 studies in patients with normal left ventricular wall motion demonstrated a hypokinetic septum on the standard echo recording. In the group with abnormal wall motion, all 11 patients with abnormal septal motion by echo had abnormal motion of the anterolateral or lateral left ventricular wall detected by videotracking. This may be why the ultrasound technique rarely underestimates the ejection fraction.

In an earlier study,\(^{10}\) we examined ultrasound and cineangiographic measurements of left ventricular performance in patients with wall motion abnormalities of varying etiology and found a better correlation between these measurements than in the present study of patients with wall motion disorders resulting exclusively from myocardial infarction. The majority of the patients previously studied with coronary artery disease or primary myocardial disease had either localized areas of akinesia or hypokinesis or diffuse hypokinesis involving the entire left ventricle. The latter abnormality is included in the standard echo recording because of its uniform nature, and thus is representative of over-all left ventricular function. A small localized hypokinetic area, on the other hand, may not lead to major functional changes in the entire left ventricle and the ejection fraction by the two methods may be more closely correlated than in patients who have more severe and extensive wall motion abnormalities. Thus, in the seven patients with either diffuse hypokinesis or localized hypokinesis, there was a strong correlation between the isotope and echo measurements of ejection fraction (\(r = 0.79\)).

Measurement of the ejection fraction from the radionuclide left ventricular time-activity curve is not without potential errors. It appears to slightly overestimate very low ejection fractions or underestimate high ejection fractions when compared to cineventriculography.\(^{17, 18}\) In addition, inaccurate assignment of the regions of interest to the left ventricular blood pool and the noncardiac background structures and improper correction for background interference may lead to an over or underestimation of the ejection fraction (see Methods). However, in our previous study utilizing this radioisotope technique, there was an excellent correlation (\(r = 0.94\)) between the ejection fraction determined by radionuclide angiocardiography and the ejection fraction by biplane left ventricular cineangiography.\(^{19}\) Furthermore, there was no difference in the correlation between the two techniques in the nine patients with abnormal wall motion by cineangiography as compared to the 11 patients with normal wall motion. In addition, the isotope technique appeared to accurately estimate ejection fraction in the three patients in the previous study who had cineangio-

Our results are consistent with the data reported by Teichholz and associates (21) who noted errors in the calculation of left ventricular ejection fraction by standard time-motion echocardiography compared with biplane cineangiography in 14 patients with left ven-
tricular asynery.

The data obtained in the present study indicate that standard echocardiographic measurements of the ejection fraction, when compared to radionuclide angiography, tend to overestimate left ventricular performance in patients with myocardial infarction associated with anterolateral wall motion abnormalities.

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Correction

Chaitman et al.: Circulation 52: 420, 1975. On page 424, the legend to figure 4 belongs with figure 5 and the legend to figure 5 belongs with figure 4.

Jaffe: Circulation 52: 714, 1975. On page 719 the relevant portion of figure 6 was left out. The correct figure will be printed with part 2 of this report to be published in the January 1976 issue of Circulation.
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