Left Ventricular Performance after Myocardial Infarction
Assessed by Radioisotope Angiocardiography

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SUMMARY
Radioisotope angiocardiography was performed by peripheral venous or pulmonary arterial injection of $^{99m}$Tc pertechnetate in 64 patients with acute myocardial infarction. End-diastolic volume determined with this technic averaged $101 \pm 7 \text{ (} \pm \text{ SEM)} \text{ ml/m}^2$ and was elevated ($>90 \text{ ml/m}^2$) in 47 patients. Initial ejection fraction (EF) averaged $0.38 \pm 0.03$ and was reduced ($<0.52$) in 58 patients. The extent of diameter shortening at the minor left ventricular equator determined from the isotope angiocardiograms was depressed in 51 patients, a reduction which was not consistently related to the site of infarction determined electrocardiographically. In 53 survivors EF averaged $0.40 \pm 0.02$, compared to $0.26 \pm 0.07$ ($P < 0.05$) in 11 patients who died within 1 month. EF correlated inversely with infarct size estimated by analysis of serial changes in serum CPK activity ($r = 0.71, n = 42$). Of the 64 patients with acute infarction, 47 exhibited abnormal wall motion detectable by the radionuclide technic and confirmed by radarkymography. Serial radioisotope angiocardiograms (6 hours–1 month) showed improvement of cardiac function in 30 of 53 patients, with no change in 12, and deterioration in 13 patients. Results obtained indicate that radioisotope angiocardiography performed by peripheral intravenous injection of $^{99m}$Tc pertechnetate can be performed safely, rapidly, and serially without hemodynamic perturbation to assess left ventricular performance in patients critically ill with acute myocardial infarction.

Additional Indexing Words:
- Ejection fraction
- Infarct size
- Ventricular performance
- Ischemic heart disease
- Coronary artery disease
- Cardiac function

The use of contrast media to measure ventricular volume, ejection fraction, and fiber shortening velocity has facilitated assessment of left ventricular performance in patients with cardiovascular disease. However, because cardiac catheterization is required, and because contrast media may impair myocardial function transiently, serial studies in seriously ill patients are impractical. Radioisotope angiocardiograms obtained with left ventricular injections of radioisotope delineate left ventricular volumes accurately. Since assessment of ventricular performance is a useful index of prognosis after acute myocardial infarction, this study was designed to determine whether radioisotope angiocardiography performed with peripheral venous or pulmonary arterial injections of radioisotope can be used to estimate accurately and serially left ventricular volume and ejection fraction in patients with this disorder. The primary purpose of the investigation was not to characterize ventricular performance per se in these patients, but rather to determine whether application of this relatively innocuous technic provides useful information and is readily applicable for acute and serial studies in these critically ill patients.

Methods and Materials
Radioisotope angiocardiograms were obtained in 64 patients with acute myocardial infarction and in 15 patients with angina pectoris. The diagnosis of acute myocardial infarction was established by the presence of at least two of the following criteria: (1) a history of...
RADIOISOTOPE ANGIOCARDIOGRAPHY

With the use of an ECG-gating device six consecutive images at either end-systole or at end-diastole were summed and then displayed on the playback oscilloscope of the Nuclear Chicago-Pho Gamma III. A 40-50 msec gate at the onset of the QRS complex was used to obtain images at end-diastole, and a similar gate beginning at the apex of the T wave was employed to obtain images at end-systole. Selected left ventricular images were obtained from consecutive beats while ventricular rhythm was regular to avoid distortion due to arrhythmia. Effects of respiratory movement on the radioisotope images were minimized by encouraging the patients to maintain end-expiration during selection of the summed images. Summed images were photographed on 35-mm film, projected on a flat surface, and their areas determined by planimetry (fig. 2). Single-plane volumes were calculated according to Sandler and Dodge. The difference between end-systolic and end-diastolic volumes was used to calculate stroke volume (SV), and the ratio SV to end-diastolic volume was used to calculate ejection fraction. The left ventricular minor equatorial diameter was obtained by bisecting a line drawn from the midpoint of the aortic or the mitral valve plane to the apex. The extent of diameter shortening was calculated from the difference between the minor equatorial diameters at end-diastole and at end-systole. Because all calculations were derived from summed images, determinations of ventricular volumes represent the average of six consecutive beats. Measurements were corrected for magnification by reference to a grid consisting of concentric lead rings 5 and 10 cm in diameter, placed 15 cm from the scintillation-camera detector surface corresponding to the level of the heart.

After peripheral venous injection of isotope the frontal-plane projection of the aortic plane is often difficult to outline. Fortunately, the left ventricular cavity, including the aortic valve plane, can be visualized readily after peripheral venous injections of

typical prolonged chest pain; (2) evolution of transmural electrocardiographic changes; and (3) characteristic serial elevations of serum enzymes (CPK, SGOT, and/or LDH). In 55 of the 64 patients with acute myocardial infarction, serial studies employing intravenous injections were obtained from 6 hours to 1 month after onset of the acute episode. In the 15 patients without acute myocardial infarction who underwent selective left ventriculography during diagnostic cardiac catheterization, radioisotope angiography was performed within 24 hours prior to catheterization in order to compare results obtained with selective injection of contrast media to those obtained with the radioisotope procedure. The radioisotope study was performed first, to avoid depression of contractility influencing results in the radioisotope study which may persist after studies with contrast medium injection.

Radioisotope angiocardiograms were performed with patients in the supine position as follows: 99m-Tc Technetium [15 mCi (sodium pertechnetate) in 1 ml saline] was injected into a peripheral vein (39 patients) or into the pulmonary artery via a Swan-Ganz catheter (25 patients) followed by a flush with 10 ml of 5% dextrose and water. The radioisotope angiocardiogram was obtained with the use of an Anger scintillation camera (Nuclear Chicago-Pho Gamma III) equipped with a 4000 parallel hole, low-energy collimator placed in the anterior or left lateral position. All scintillation-camera image data were recorded in “real time” on magnetic tape using a Nuclear Chicago Data/Storage Accessory. Electrocardiograms were recorded simultaneously on the audio track of the recorder. The whole body absorbed radiation dose did not exceed 0.18 rad/15-mCi dose.

Data Analysis

The recorded scintiscans were replayed with the simultaneously recorded electrocardiogram (fig. 1).
isotope when the left lateral projection is employed (fig. 2). Therefore, in order to spare patients with uncomplicated myocardial infarction cardiac catheterization, we utilized peripheral venous injections and obtained scintiscans with the scintillation camera in the left lateral position.

To determine whether volume calculations based on lateral projections correspond to those calculated from biplane projections, conventional contrast media angiograms of 46 patients were reviewed. In addition, left ventricular volumes and ejection fractions were calculated from the biplane formula and compared to values calculated from lateral silhouettes alone. Twenty-four patients had well-documented coronary artery disease; 22 of these exhibited severe wall motion abnormalities.

**Results**

**Left Ventricular Volumes and Ejection Fraction Calculated from the Left Lateral Compared to Biplane Projections**

Left ventricular end-diastolic volume (LVEDV) values obtained by the biplane cineangio graphic analysis in 46 patients correlated closely with results calculated from the lateral projection alone in the same patients as shown in figure 3. Ejection fractions calculated by the two methods correlated closely as well (fig. 3). The regression lines (least-squares method) for these data are $Y = 0.95X + 23$, $r = 0.95$, $n = 46$ (LVEDV); and $Y = 0.98X + 0.03$, $r = 0.91$, $n = 46$ (ejection fractions). Thus, the lateral projection serves well as the basis for calculation of ventricular volumes and ejection fraction even in patients with severe wall motion disorders.

**Comparison between Results from Contrast Medium and Radioisotope Angiocardiography**

In figure 4, the left ventricular end-diastolic volume obtained from the radioisotope study is compared to the end-diastolic volume calculated by an independent observer from the contrast medium cineangiogram in the same patients. Results from the two methods were linearly related ($Y = 0.95X + 19$, $r = 0.87$, $n = 15$). Similarly, ejection fractions calculated by both technics were comparable ($Y = 0.90X + 0.01$, $r = 0.94$, $n = 15$). In 10 of 15 patients studied by contrast medium and radioisotope angiocardiography, abnormal wall motion was present, verified by recognition of paradoxic pulsation by radarkymography, and readily detected by contrast medium and radioisotope angiography which revealed dyskinetic portions of the ventricular wall. Thus, left ventricular volumes and ejection fraction values calculated from scintiscans obtained after a peripheral venous injection of radioisotope correlate closely with values obtained by left ventriculography even when wall motion abnormalities are present.

**Radioisotope Angiograms in Patients with Acute Myocardial Infarction**

One hundred twelve radioisotope angiograms were obtained during the acute phase in 64 patients with acute myocardial infarction. Initial values for left ventricular end-diastolic volume in these patients averaged 101 ± 7 (±SEM) ml/m² (range 52–206) and was abnormally elevated (>90 ml/m²) in 47 patients. Initial ejection fraction averaged 0.38 ± 0.03 with a range of 0.08–0.67 and was reduced <0.52 in 58 patients. The extent of diameter shortening at the minor left ventricular equator averaged 18.6% ± 1.4% and was reduced <25% in 50 patients. The magnitude of the reduction was not related to electrocardiographic site of infarction. Abnormal wall motion was detected in 47 of the initial 64 studies in patients with acute myocardial infarction (fig. 2) and verified in all cases by recognition of paradoxic motion by radarkymography. Because of its location, wall motion disorder appeared to contribute to the calculated decreased diameter shortening in only 16 patients. Corresponding values in six hospitalized patients without cardiovascular disease studied by radioisotope angiography for left ventricular end-diastolic volume, ejection fraction, and extent of diameter shortening were 86 ± 12

**Figure 2**

End-systolic (left) and end-diastolic (right) images in the lateral projection obtained after peripheral venous injection of $^{99m}$technetium in a patient with acute myocardial infarction. Anterior wall akinesis is apparent. (Bottom) The silhouettes are outlined in order to depict the planimetered area used for volume and ejection fraction calculations. Papillary muscle images were not excluded from the planimetered areas. Since Sandler and Dodge have demonstrated that the radii in the posteroanterior and lateral projections are virtually identical, the formula for single frontal-plane volume calculations proposed by these investigators has been applied to volume calculations in the lateral (L) projection: $V_L = 4/3\pi \times (D_L/2)^2 \times (L/2)$; $D_L/2$ = chamber radius in the lateral projection; and $L_L$ = the longest measured length in the lateral projection. The lateral chamber radius is derived from $D_L/2 = 2A/\pi L_L$; $A$ = the planimetered area of the lateral left ventricular image. $A_0$ = aorta; $L_A$ = left atrium.
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Esophageal esophagography. These impaired left ventricular performance readily observed in patients with acute myocardial infarction exhibit impaired left ventricular performance readily demonstrable by radioisotope angiography.

Figure 3

End-diastolic volume (left) and ejection fraction (right) calculated from the lateral cineangiogram compared with values obtained by the biplane method in the same patient. The regression lines best fitting these data (least-squares method) are shown. As can be seen, results obtained with the two methods of analysis correlated closely.

ml/m², 0.60 ± 0.02, and 31 ± 1.2%, respectively, similar to normal values obtained by conventional ventriculography. These results indicate that most patients with acute myocardial infarction exhibit impaired left ventricular performance readily demonstrable by radioisotope angiography.

The National Heart and Lung Institute Myocardial Infarction Research Units (MIRU) have utilized a clinical classification based on the presence of complications. Class I patients exhibit no clinical evidence of impaired left ventricular performance; class II patients manifest mild-to-moderate left ventricular failure; class III, overt pulmonary edema; and class IV, cardiogenic shock. When the severity of impaired ventricular performance detected by radioisotope angiography in the present study was compared to MIRU clinical class, the results depicted in figure 5 were obtained. Although contrast medium ventriculography affords better resolution than isotope angiograms following peripheral injection, the radioisotope studies provided objective evidence of impaired ventricular performance in these acutely ill patients which corresponded to the severity of their clinical state.

Correlations between Abnormal Radioisotope Angiograms and Severity of Myocardial Infarction

Ejection fraction calculated from the initial radioisotope angiograms was compared to infarct size determined by analysis of serial changes in serum creatine phosphokinase activity as previously described in 42 patients. In figure 6 initial ejection fraction is compared to infarct size. Twenty-three patients with small infarcts (<65 CPK gEq) had a mean initial ejection fraction of 0.47 ± 0.03, compared to 0.29 ± 0.04 in the 19 patients with infarcts larger than 65 CPK gEq (P < 0.01).

The average value for the lowest ejection fraction calculated from isotope angiograms in the 53 patients with acute myocardial infarction who survived for at least 1 month was 0.40 ± 0.02 compared to 0.26 ± 0.07 in 11 patients who died acutely (P < 0.05). The lowest ejection fraction in each of the nonsurvivors (excluding two nonsurvivors who died of unrelated causes) averaged even less, i.e. 0.19 ± 0.06. Twelve patients exhibited ejection fractions lower than 0.25 during the acute phase. Seven of these died during hospitalization and one died 5 months after the acute infarct with severe congestive heart failure. Of the four survivors in this group, one patient has been lost to follow-up.

Figure 4

End-diastolic volume (left) and ejection fraction (right) calculated from radioisotope angiograms compared to values obtained in the same patient with contrast medium cineangiography.

Figure 5

Ejection fraction (mean ± S.E.M) calculated from the initial radioisotope angiograms obtained in 64 patients with acute myocardial infarction compared to initial clinical class. Values in class II, III, and IV patients differed significantly from those in class I patients (P < 0.01, 0.1, 0.01, respectively).

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follow-up and the other three exhibit significant cardiovascular disability.

Serial Radioisotope Angiocardiograms

Fifty-five patients were studied serially from 6 hours to 1 month after the initial study. Improvement in left ventricular function occurred in 30 as reflected by an increase in ejection fraction. Thirteen patients manifested deterioration of left ventricular performance. An example of changes in ejection fraction determined from serial radioisotope angiocardiograms is shown in figure 7.

Discussion

Determination of left ventricular volume and ejection fraction with contrast media is an accepted mode of evaluating cardiac performance. However, left ventriculography necessitates cardiac catheterization and injection of hypertonic contrast media which depress myocardial function. For these reasons, such technics are not usually suitable for assessment of left ventricular function or serial evaluations in patients acutely ill with myocardial infarction.

Radioisotope angiocardiography is a useful diagnostic technic in patients with chronic cardiovascular disease. With the use of the Anger scintillation camera and a video storage system, Mason and his associates visualized the central circulation by selective injection of sodium pertechnetate at the time of diagnostic cardiac catheterization. In addition, they viewed selected phases of the cardiac cycle by the use of an electrocardiographic gating discriminator. With selective injections of radioisotope into the left ventricle of dogs, others have shown that end-diastolic volume calculated from radioisotope angiocardiograms corresponds to volume determinations obtained by left ventricular pressure-volume curve analysis.

In the present study, we extended the application of radioisotope angiocardiography to critically ill patients with acute myocardial infarction in order to assess left ventricular performance both acutely and serially. Each study took approximately 30 sec to perform, produced no discomfort to the patients, and did not lead to hemodynamic disturbance. Results demonstrated that depression of left ventricular performance associated with acute myocardial infarction is reflected by elevated end-diastolic volume, reduced ejection fraction, and decreased diameter shortening detectable by radioisotope angiocardiography. Previous cardiac catheterization studies of left ventricular function in patients with

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**Figure 6**

Initial ejection fraction calculated from radioisotope angiocardiograms compared to estimated infarct size determined by the UCSD serial CPK method in 41 patients with acute myocardial infarction. The regression line (least-squares method) best fitting these data is $Y = -0.0032X + 0.58$, $r = -0.73$, $n = 41$.

**Figure 7**

Serial changes in ejection fraction in a patient with acute myocardial infarction determined from radioisotope angiocardiograms. Improvement of ejection fraction during therapy with a Cardiassist (Medical Innovations, Inc.) external pressure circulatory assist device is readily demonstrable and probably reflects the effect of diminished afterload as well as possible improvement in contractility.
acute transmural myocardial infarction have demonstrated that left-sided filling pressures are usually elevated.\textsuperscript{15, 16} Indirect assessment of left ventricular performance by analysis of systolic time intervals has not been uniformly consistent.\textsuperscript{17–19} Our results suggest that radioisotope angiography performed via a peripheral venous bolus injection of isotope provides a useful means for assessment of left ventricular performance applicable to serial determinations in patients with acute myocardial infarction. Although resolution of cardiac images is less satisfactory than that possible with contrast media, the radioisotope technic is often more convenient and relatively free from hazard in this setting.

Left ventricular performance is affected by several factors in patients with acute infarction, especially alterations in left ventricular filling pressure sometimes related to diuretic therapy and altered contractility due to the infarct itself and to secondary changes such as hypoxemia. Nevertheless, it has been proposed recently that infarct size and ejection fraction may be linearly related.\textsuperscript{20} The present results support this hypothesis. Assessment of infarct size by the UCSD, CKP analysis method and application of radioisotope angiography to patients with acute myocardial infarction permitted objective evaluation of the relationship in patients with acute infarction for the first time. Our results (fig. 6) indicate that, indeed, these two parameters are linearly related, although not unexpectedly some scatter exists probably in part because of determinants of ejection fraction other than infarct size per se such as preload and afterload.

The close correlation between contrast medium cineangiographic and radioisotope angiographic data agrees well with results reported by others in patients with chronic cardiovascular disease.\textsuperscript{22, 23} Our results indicate that radioisotope angiography performed by peripheral intravenous bolus injection is helpful in the assessment of left ventricular performance without the need for cardiac catheterization or contrast medium injection in patients critically ill with acute myocardial infarction.

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