Measurement of Right and Left Ventricular Ejection Fractions by Radionuclide Angiocardiography in Coronary Artery Disease*

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Utilizing a dynamic radionuclide method, the right and left ventricular ejection fractions were measured in 96 men with arteriographically defined coronary arterial disease and in 14 normal subjects. The radionuclidically estimated right ventricular ejection fraction (RVEF) correlated with the LVEF measured with biplane cineangiocardiographic studies (r = 0.80; n = 43), and the left ventricular ejection fraction (LVEF) measured from radionuclide data have been shown to correlate with the LVEF from single-plane cineangiocardiographic studies (r = 0.89; n = 60). The mean normal RVEF was 0.57 ± 0.01 (SE) (range, 0.51 to 0.64), and the mean normal LVEF was 0.66 ± 0.01 (range, 0.57 to 0.74). The LVEF was decreased in the men with coronary arterial disease and isolated obstruction of the left anterior descending coronary artery, double-vessel disease, and triple-vessel disease, but was normal in those with isolated right coronary disease. The RVEF was normal in each of these groups, except those with triple-vessel disease. Myocardial infarction was associated with impairment of LVEF, although some patients without myocardial infarction had depressed LVEF. The RVEF was preserved in patients with infarction, except those with multiple myocardial infarctions. Thus, impaired LVEF in coronary arterial disease is associated with myocardial infarction, and RVEF is relatively preserved except in multiple-vessel disease and myocardial infarction and in association with impaired LVEF.

Several studies have suggested that in patients with coronary disease, mortality is determined by left ventricular function,1,2 myocardial infarction,1-3 and the extent of coronary arterial obstruction.1,4,5 Thus, evaluation of left ventricular performance and determination of the severity and extent of coronary arterial obstruction should have prognostic importance for patients with coronary disease.

Several methods have been developed to measure the left ventricular ejection fraction (LVEF), including contrast ventriculography6 and radionuclide angiocardiography,7,8 and these techniques have been successfully applied to patients with coronary arterial disease.9,10 Although contrast ventriculographic methods have been developed to measure right ventricular volume and right ventricular ejection fraction (RVEF),11-13 they have thus far been applied only to a few patients with coronary disease.14

We have developed a dynamic radionuclide method which accurately measures the LVEF15 and have applied this technique to a group of patients with arteriographically established coronary arterial disease. In addition, the RVEF was measured in these patients using a modification of this radionuclidic technique.

Patients

The RVEF and LVEF were measured in 96 men patients (mean age, 49 years; range, 29 to 64 years) who had coronary arteriographic evidence of coronary arterial disease and in 14 normal men subjects who underwent coronary arteriographic studies for evaluation of chest pain. The patients gave their informed consent for the performance of the radionuclide study as well as the cardiac catheterization procedure. All patients had stable symptoms; patients with preinfarctional angina or recent myocardial infarction were excluded.

Methods

In these 110 men, coronary arteriographic studies were undertaken using the Sones technique.16 Of the 96 men with coronary disease, all had at least one area of greater than 50 percent narrowing of at least one major coronary artery,
either the right, the left anterior descending, or the left main circumflex coronary artery or its marginal branches. The patients without coronary disease had no area of greater than 20 percent narrowing in any major coronary artery or branch.

For purposes of classification, the men with coronary disease were grouped as having isolated involvement of the right coronary artery, isolated obstruction of the left anterior descending coronary artery, double-vessel disease (including men with obstructions of the left anterior descending and right coronary arteries, of the left anterior descending and left circumflex coronary arteries, and of the right and left circumflex coronary arteries), and triple-vessel obstructive disease. Eleven men had obstruction of the left main coronary artery, and all had additional obstructive lesions in the right, anterior descending, and circumflex coronary arteries and were grouped with the triple-vessel patients.

Myocardial infarction was defined as pathologic Q waves (0.04 second) in at least two leads on the electrocardiogram obtained at the time of cardiac catheterization. Infarctions were classed as either inferior (including true posterior) or anterior (including anterolateral and superior lateral infarctions). The ECGs were normal in the patients without coronary disease.

The RVEF and LVEF were measured using a radionuclide technique. In the cardiac catheterization laboratory a Swan-Ganz catheter was advanced with fluoroscopic control to a pulmonary arterial wedge position (balloon deflated) in the right lower lobe of the lung. The patient was placed under an Anger scintillation camera in the 20° right anterior oblique position with the tomographic collimator (20° fixed slant) to achieve a 40° right anterior oblique projection.

For left ventricular imaging, 8 milligrams of 99m-technetium pertechnetate in 1 to 1.5 ml of saline solution was injected into the catheter and flushed with 5 ml of saline solution. Following left cardiac imaging, the catheter was withdrawn such that the tip was in the superior vena cava, and a second injection of 5 milligrams of 99m-technetium pertechnetate was injected and flushed for right cardiac imaging.

The system which accomplished the collection, storage, playback, and analysis of the scintigraphic data consisted of a commercially available Anger camera (Pho/Gamma HP, Searle Radiographics Inc.), which was interfaced to a computer (PDP-12, Digital Equipment Corp.). For data collection a magnetic disk was used for semipermanent storage of successive 32 x 32-element images at a framing rate of 20/sec. After data collection, analysis began with playback to observe the approximate times that radioactivity first entered the atrium and ventricle. This information was used together with the ability of the computer to form composite sum or difference images. These summed images provided improved anatomic definition which was helpful in defining areas of interest (valvar planes) for extraction of ventricular time-activity curves.

Using the computer, we defined four areas of interest: the left ventricle, the right ventricle, and two respective chamber-background areas. The cardiac-chamber areas of interest were constructed such that they just exceeded the end-diastolic area of the chamber. The background areas were defined as 2-cm wide semiannular rings which surround the ventricles avoiding the areas of the great vessels.

Time-activity curves were extracted from the left and right ventricular areas of interest and their background areas. The background curve was smoothed and multiplied so that its tail was tangential to that of the uncorrected chamber curve. The ejection fraction for the ventricle was computed from the fractional fall in the background-corrected ventricular time-activity curve between successive points of the end of diastole and the end of systole (Fig 1). This calculation was performed using as many beats as possible and averaged. Two beats were always available for analysis, and the difference between the calculated ejection fraction of the beats selected was always less than 10 percent. Beats were selected for analysis if clear end-diastolic and end-systolic points could be identified (Fig 1).

The LVEF determined from this radionuclidian method has been shown to correlate (r = 0.89; n = 60; P < 0.001) with the LVEF measured from single-plane contrast ventriculograms.

For validation of the radionuclide technique of measuring the RVEF, an area-measurement method of Arcilla et al. was used to analyze cineventriculograms. Forty-three patients were studied in the postabsorptive state after sedation with oral administration of 25 mg of diphenhydramine hydrochloride and 5 to 10 mg of diazepam. Included in these patients were 14 men with normal coronary arteriograms, 24

![Figure 1. Background-corrected time-activity curve from right ventricular area of interest. Ejection fraction is calculated from fractional fall in counts from end of diastole (D) to end of systole (S) divided by end-diastolic count-rate; its value is 0.47 for indicated beat, 0.49 for preceding beat, and 0.49 for following beat (mean, 0.48).](image1.png)

![Figure 2. Comparison of RVEF determined from radionuclide data and from area measurement of right ventricular cineangiograms.](image2.png)

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men with coronary disease, and five with cardiomyopathy. The contrast cineventriculograms were performed sequentially in steep left anterior oblique and anteroposterior projections with a total injected dose of 48 to 60 ml of a solution of meglumine diatrizoate (66 percent) and sodium diatrizoate (10 percent) (Renografin-76, Squibb) injected into the superior vena cava over three to four seconds. An Arrilflex-type camera at a speed of 60 frames per second was used for filming after power injection of the contrast medium. Subsequent to the contrast study (at least 30 minutes), left and right cardiac imaging was performed.

The outline of the right ventricle was traced from a series of individual cineventriculographic frames of one cardiac cycle using a Tagarno viewer. The maximal and minimal areas in both projections were designated as the right ventricular end-diastolic area and end-systolic areas, respectively, and were selected for volume computation. For calculation of right ventricular volume (V), the planimetered areas of the left anterior oblique and anteroposterior projections were used, together with the maximum apex-base dimension (L) in the left anterior oblique projection as:

\[ V = \pi L M_{150} M_{30}/4 \]  
(1)

where M, the minor axis, was calculated from the planimetered areas (A) using the ellipse formula as:

\[ M_{150} = 4 A_{150}/\pi L \]  
(2)

and:

\[ M_{30} = 4 A_{30}/\pi L \]  
(3)

Using this method, Arcilla et al. noted good correlation between contrast ventriculographic studies and right ventricular casts (r = 0.94).

**RESULTS**

In the 43 patients who had the RVEF measured by both the radionuclide technique and cineventriculographic studies, the correlation between these two techniques was good (r = 0.80) (Fig 2). In the 14 normal men, the mean RVEF determined with radionuclide data was 0.57; and using as the normal range two standard deviations from the mean, the normal range was calculated as 0.51 to 0.64. Normal men had a mean LVEF of 0.66 and a normal range of 0.57 to 0.74.

For the 96 men with coronary arterial disease, a relationship between the LVEF and the number of obstructed coronary arteries was apparent (Fig 3). Of the seven men with coronary disease limited to the right coronary artery, all had normal values for LVEF. The mean LVEF was decreased (0.53 ± 0.03) in men with isolated obstruction of the left anterior descending coronary artery. Nine (60 percent) of these 15 had impairment of the LVEF. Of the 23 men with involvement of two coronary arteries, the LVEF averaged 0.52 ± 0.02, and 14 (61 percent) had left ventricular dysfunction. Fifty-one men had involvement of three arteries, and the LVEF was depressed in 43 (84 percent) of these (mean, 0.42 ± 0.02).

Electrocardiographic evidence of myocardial infarction was associated with impairment of LVEF. Of the 51 men with triple-vessel coronary disease, 42 had evidence for at least one myocardial infarction. The mean LVEF was 0.51 ± 0.04 in the nine men with triple vessel disease who had not had an infarction, but was 0.40 ± 0.02 in the 42 with infarction (P < 0.001). Of the 23 men with double vessel obstruction, the mean LVEF was 0.57 ± 0.02 in the 11 without infarction, but was 0.47 ± 0.03 in the 12 men with infarction (P < 0.001). Similarly, for the 15 men with isolated obstruction of the left anterior descending coronary artery, there was a significant difference in the mean LVEF between men with infarction (0.48 ± 0.02) and those without (0.60 ± 0.04; P < 0.001). Two men had evidence for inferior infarction and had coronary disease limited.

**Figure 3.** Relationship between LVEF and location and extent of coronary artery disease. Solid circles identify patients with electrocardiographic evidence of myocardial infarction. Means are indicated by horizontal lines. Normal mean and range are indicated at left R, isolated obstruction of right coronary artery; LAD, isolated obstruction of left anterior descending coronary artery; ×2, double vessel disease; and ×3, triple vessel disease.
to the right coronary artery, and both had a normal LVEF, as did all of the other five with isolated right coronary disease but without infarction. Thus, LVEF was depressed in all groups of men with coronary disease except those with isolated right coronary obstruction.

The RVEF was preserved relative to the LVEF in these patients (Fig 4). In the men with isolated right coronary disease, the mean RVEF (0.59 ± 0.02) was normal and not significantly different from normal (0.57 ± 0.01), and all seven had a normal RVEF. Of the 15 with isolated involvement of the left anterior descending coronary artery, the mean RVEF was not significantly different from normal (0.57 ± 0.001), and 12 (80 percent) of the 15 had a normal RVEF. In the 23 men with double-vessel disease, the mean RVEF was 0.56 ± 0.02, which was not significantly different from normal, and 19 (83 percent) had a normal RVEF. Only in the group with triple vessel disease was the mean RVEF depressed (0.52 ± 0.02); P < 0.001); but even in these men, 29 (57 percent) of 51 had a normal RVEF.

There was a significant difference between the mean RVEF of the 42 men with triple vessel coronary disease and electrocardiographic evidence for myocardial infarction (0.51 ± 0.02) and that of the nine without infarction (0.55 ± 0.03; P < 0.001). In the other three groups of patients, there were no significant differences in the mean RVEF between men with infarction and without (double vessel involvement, 0.56 ± 0.03 vs 0.56 ± 0.02; isolated involvement of the left anterior descending coronary artery, 0.55 ± 0.02 vs 0.56 ± 0.02; and isolated involvement of the right coronary artery, 0.60 vs 0.59, respectively). Thus, the mean RVEF was normal in all groups of patients except those with triple vessel disease.

The RVEF was preserved relative to the LVEF in patients with infarction (Fig 5). In men without a history of infarction, the mean RVEF was normal (0.56 ± 0.01) and not significantly different from normal. Only three (9 percent) of 32 had depressed RVEF, and one of these had triple vessel obstruction. The mean RVEF was 0.52 ± 0.01 in the 64 with electrocardiographic evidence of infarction, which was significantly decreased as compared with normal (P < 0.001). Twenty-six (41 percent) of the 64 patients with infarction had a depressed RVEF; and of these, 20 (77 percent) had triple vessel disease.

**Figure 4. Relationships between RVEF and extent and location of coronary arterial disease. Solid circles identify patients with electrocardiographic evidence of myocardial infarction. Means are indicated by horizontal lines. Normal mean and range are indicated at left. R, Isolated obstruction of right coronary artery; LAD, isolated obstruction of left anterior descending coronary artery; \( \times 2 \), double vessel disease; and \( \times 3 \), triple vessel disease.**

**Figure 5. Relationship between RVEF and occurrence, location, and extent of myocardial infarction. Solid circles indicate patients with triple vessel disease.**

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In men with inferior infarction, the mean RVEF was normal (0.56 ± 0.02) and not different from normal. Seven (24 percent) of these 29 had a depressed RVEF; and of these, four had triple vessel disease. Of the 17 with anterior infarction, the RVEF was depressed in six (28 percent), and the mean RVEF (0.55 ± 0.02) was significantly different from normal (P < 0.05). Three of the six with a depressed RVEF had triple vessel disease. The RVEF was decreased in men with multiple infarctions (0.45 ± 0.02; P < 0.001), and all had triple vessel obstruction. Thirteen (72 percent) of the 18 had right ventricular dysfunction. Thus, RVEF was preserved in all groups of patients, except those with multiple infarctions.

The RVEF correlated with the LVEF (r = 0.61) in these 96 men with coronary disease. In none of these men was right ventricular infarction recognized clinically at the time of myocardial infarction, and there was no case in which isolated right ventricular dysfunction was observed.

**Discussion**

The radionuclide method for measurement of the RVEF is similar in concept to that which we have developed for estimation of the LVEF. Ejection fraction is measured as the fractional fall in count rate during washout of tracer from the ventricle. To correct for the effect of scattered radiation in the ventricular time-activity curve, an empirical correction was applied to the right ventricular time-activity curve in a fashion similar to that for the left ventricle.

This radionuclide technique seems to provide an accurate method for measuring the RVEF, as correlation between the radionuclide method and contrast cineventriculographic studies is good. The advantage of a radionuclide method for measuring the RVEF would be the opportunity to perform serial studies without concern for the effects of contrast.

The data on left ventricular performance confirm the finding of other investigators that past myocardial infarction is associated with impairment of LVEF. The data also suggest a relationship between the extent of coronary arterial obstruction in respect to the number of vessels involved and the LVEF, which confirms the findings of Moraski and associates. The mean LVEF was progressively reduced for groups of patients with isolated involvement of the left anterior descending coronary artery, double vessel disease, and triple vessel obstruction, and was normal in patients with isolated right coronary disease. The LVEF was reduced in each of these groups of patients, except those with isolated right coronary disease, in the absence of infarction, but most patients with impaired ejection fraction had infarctions. For each of these groups, patients with infarction had lower mean ejection fractions than those without infarction. Thus, myocardial infarction, other than inferior infarction in association with isolated right coronary disease, seems to be associated with impairment of left ventricular performance.

Right ventricular performance was generally preserved in these patients with coronary disease. The mean RVEF was reduced only in patients with multiple episodes of infarction. Right ventricular performance tended to be preserved, except in patients with triple vessel coronary disease; and in these patients and in patients with less extensive coronary obstruction, most with impairment of the RVEF had infarction.

Wells and Befeler were able to identify 13 patients from a group of 65 with coronary disease who had hemodynamic evidence for right ventricular dysfunction in the absence of hemodynamic evidence for left ventricular dysfunction. An additional 31 patients had evidence of right and left ventricular dysfunction. These investigators used elevation of the right ventricular end-diastolic pressure above 6 mm Hg as their index of right ventricular dysfunction and a left ventricular end-diastolic pressure of greater than 12 mm Hg to indicate left ventricular dysfunction. Of the 13 with isolated right ventricular dysfunction, all but one had electrocardiographic evidence for myocardial infarction. Our data would suggest that right ventricular dysfunction, as measured by ejection fraction, can occur to a greater extent than left in a few patients with stable coronary disease but that impairment of the RVEF did not occur in patients with normal left ventricular performance. Perhaps the difference between our data and that of Wells and Befeler is the measurement used, as end-diastolic pressure can be altered by factors other than ventricular systolic performance.

Ferlinz and associates have observed impairment of the RVEF in patients with right coronary obstruction, but normal RVEF in patients with coronary arterial disease which did not involve the right coronary artery. Their data are not in agreement with ours in that all of our patients with isolated right coronary disease had a normal RVEF, and three patients with isolated disease of the left anterior descending coronary artery had impaired RVEF. In addition, many of our patients with double and triple vessel obstruction involving the right and left coronary arteries had a normal RVEF.

In a recent report, Cohn et al described six patients with acute myocardial infarction and
hemodynamic evidence suggesting more derangement of right ventricular than left ventricular performance, but all patients had hemodynamic or subsequent autopsy evidence of left ventricular dysfunction. This function would seem to support the concept in coronary disease that although right ventricular performance may occasionally be more affected than left, isolated dysfunction of the right ventricle is unusual. In addition, in autopsy studies, right ventricular infarction has often been noted but was almost always associated with infarction of the left ventricle.\textsuperscript{24,25} Isolated right ventricular infarction has been reported in only about 3 percent of autopsied patients with coronary disease.\textsuperscript{24}

The relative preservation of right ventricular performance in coronary artery disease may be due to one or more of several factors which would act to reduce the extent of infarction of that chamber.\textsuperscript{26} Coronary blood flow to the right ventricular myocardium occurs during both systole and diastole, whereas it occurs only during diastole to the left ventricle.\textsuperscript{27,28} The right ventricular myocardium is nourished directly via the thebesian vessels, and collateral coronary blood flow is more extensively developed for the right ventricle than the left.\textsuperscript{29} In addition, the work of the ventricle per gram of myocardium is ordinarily less for the right than for left ventricle.\textsuperscript{27}

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REFERENCES

5 Bruschke AUG, Proudfit WL, Sones FM: Progress study of 590 consecutive nonsurgical cases of coronary disease followed five to nine years: 1. Arteriographic correlations. Circulation 47:1147-1153, 1973
18 Steele P, LeFree M, Kirch D: Measurement of mean left ventricular shortening velocity and systolic ejection rate by computerized, radionuclide techniques. Am J Cardiol, to be published