EVALUATION OF PORTABLE RADIONUCLIDE METHOD FOR MEASUREMENT OF LEFT VENTRICULAR EJECTION FRACTION AND CARDIAC OUTPUT

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Seventeen patients with coronary artery, valvular, or myopathic heart disease were studied to determine correlations of the cardiac output and ejection fraction when comparing the results obtained with a portable probe technique using ^{113m}In with those obtained with standard methods (cineangiographic, Fick, and dye dilution). With ejection fractions ranging from 0.10 to 0.85, the coefficient of correlation was 0.90 when comparing cineangiographic and radionuclide techniques. Cardiac output determinations by the radionuclide technique also correlated well with standard methods ($r = 0.88$). The radionuclide method shows promise as an accurate, safe, and simple method in the evaluation of cardiac function at the bedside.

Of the various parameters measured to evaluate left ventricular performance, the ejection fraction appears to be the best estimator of overall pump function in patients with various forms of heart disease (*1*). Noninvasive techniques, such as echocardiography (*2*) and systolic time interval measurement (*3*), have been used to assess ventricular performance; however, neither measures ejection fraction in a manner that is unaffected by localized wall motion abnormalities such as occur in coronary artery disease. Therefore, a need exists for an accurate, safe, and simple noninvasive method of measuring overall pump function, including left ventricular ejection fraction, in patients with various forms of heart disease. For years, radionuclides have been used to obtain quantitative information on the size of various cardiac chambers and the rate of blood flow through them (*4*). The determination of cardiac output using a scintillation camera has been previously described (*5*). More recently, modifications in the scintillation probe and the use of high-frequency variation in counting rate recording from within the left ventricle have provided accurate information concerning the left ventricular ejection fraction when appropriate correction has been made for counts from surrounding tissue (*6,7*).

In this paper we report our results comparing cardiac output, left ventricular ejection fraction, and left ventricular end-diastolic volume determined by standard invasive methods with results obtained using a portable single probe to monitor the passage of a radionuclide through the arterial circulation.

METHODS

Radionuclide method. The equipment and procedures used in this study have been previously described (*6,7*). The radionuclide used is ^{113m}In. Easily elutable from a commercially available, long-lived generator (118 days), ^{113m}In has a photon energy (393 keV) that assures near isoefficiency of counting regardless of depth, and its lack of beta radiation is associated with a low body radiation dose (25 mrads/mCi). Its short half-life (100 min) allows serial studies to be performed within a short period of time without exceeding allowable radiation limits. If injected as the chloride directly into the blood stream, ^{113m}In combines quantitatively with transferrin and remains intravascular. With appropriate blood sampling, calculations of blood volume can be made.

A catheter is positioned in the superior vena cava. A cutaneous marker is placed over the estimated midpoint of the left ventricle as determined by fluroscopy or chest radiograph. A portable scintillation probe with a 5- × 5-cm sodium iodide crystal and a

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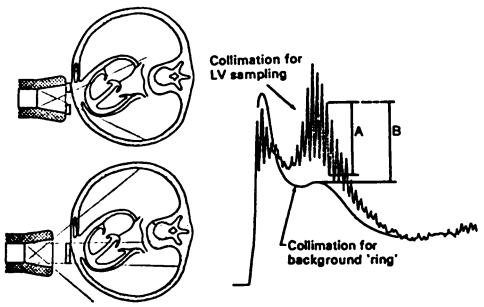

FIG. 1. Method for determining ejection fraction. Separate collimators are used to record activity from left ventricle (top left) and from background tissue surrounding left ventricle (bottom left). A/B, ejection fraction. [Modified from Steele (7) with permission.]

high-speed strip-chart recorder with a counting rate-meter with 10 million cpm capacity and time constant of less than 0.1 sec is used to record radioactivity. With the probe centered at the midpoint of the left ventricle, 1 mCi of ^{113m}In-Cl (approximately 1 ml) is injected as a bolus into the superior vena cava and the radioactivity is recorded (Fig. 1). Collimation for obtaining the left ventricular counting rate curve is provided by a 1⅜ in.-circular port in the ½ in.-lead shield. Background correction is made following a second injection of 0.5 mCi of the same radionuclide using a different collimator, which eclipses the region of the left ventricle but records paraventricular activity (Fig. 1). The eclipsing collimator is a 2$^{3}/_{16}$ in.-circular lead shield ½ in.-thick, placed 1⅜ in. out from the probe face (4⅜ in. from the detector crystal) and maintained in position by a Styrofoam cone. The recorded curve generated with the left ventricle eclipsed becomes the "background" curve when it is superimposed on that obtained with the left ventricle exposed in such a manner that their nadirs are matched. For each of the first several beats following the peak of the left ventricular curve, the differences in counting rate between maximum and minimum and between maximum and background are determined (Fig. 1). The ejection fraction is determined by averaging for the several beats the ratios of the maximum-minimum difference to the maximum-background difference. In order to determine cardiac output, the area (first pass area) under the left ventricular sampling curve is measured by planimeter from the onset of injection and following the curve representing the exponentially extrapolated washout of left ventricular activity (Fig. 1). The area under a 1-min segment of the left ventricular curve at equilibrium is similarly planimetered (equilibration area). The cardiac output is calculated as the product of the blood volume times the equilibration area divided by the first pass area (7).

Patient selection and procedure. Seventeen patients undergoing diagnostic catheterization were subjects for this study. Of these seventeen patients, five had coronary artery disease, seven had valvular heart disease, four had a cardiomyopathy, and one had coarctation of the aorta. After right- and left-sided pressures and cardiac outputs were obtained, the radionuclide studies were performed, then left ventricular cineangiography was performed in the 30-deg right anterior oblique position. The cineangiographic recording system used, together with the methods of left ventricular volume and ejection fraction determination and validation in our laboratory, has been previously described (*8*). Briefly, a video disk recorder, a light-pen unit, and a digital computer are used for computing left ventricular volumes and ejection fractions.

RESULTS

Figure 2 shows good correlation of the left ventricular ejection fraction as determined by contrast cineangiography and the radionuclide technique ($r = 0.90$). Elimination of patients with valvular heart disease does not alter this correlation. Figure 3 shows a typical record obtained from a patient with a normal ejection fraction and that of another patient with a low ejection fraction. Patients in atrial fibrillation were excluded from ejection fraction determination and correlation study since the maximum-to-minimum oscillations in ventricular activity vary considerably with changing R-R intervals. The correlation of the cardiac output using ^{113m}In and standard methods (dye dilution or Fick) is shown in Fig. 4. The inclusion of patients with valvular insufficiency

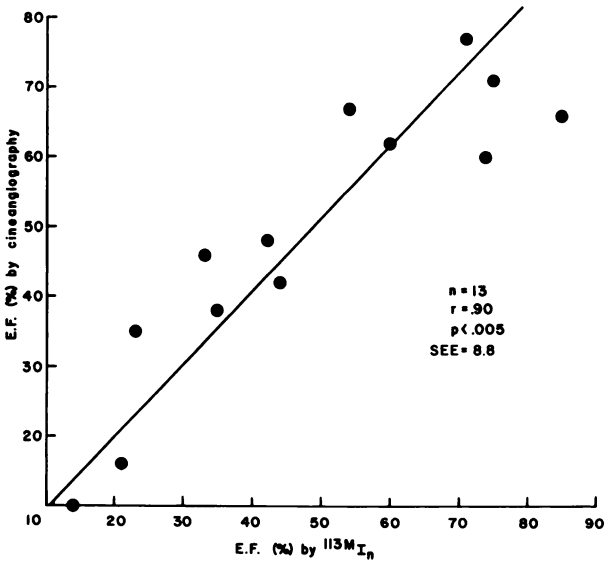

FIG. 2. Correlation of ejection fraction determined from contrast cineangiographic and radioisotope techniques. EF, ejection fraction; r, correlation coefficient; and SEE, standard error of the estimate.

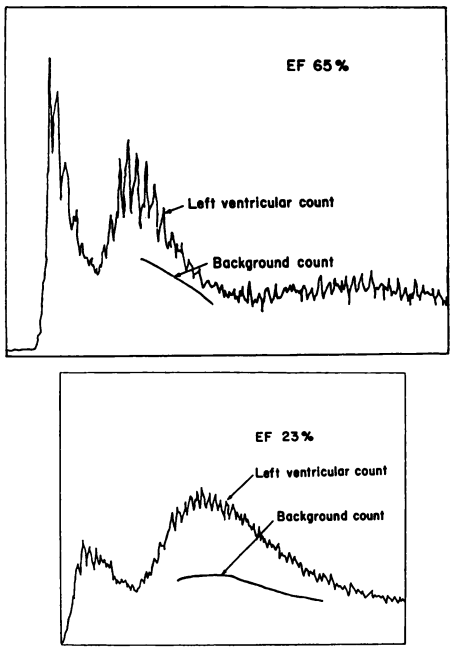

FIG. 3. Records from patient with normal ejection fraction (top) and another patient with low ejection fraction (bottom).

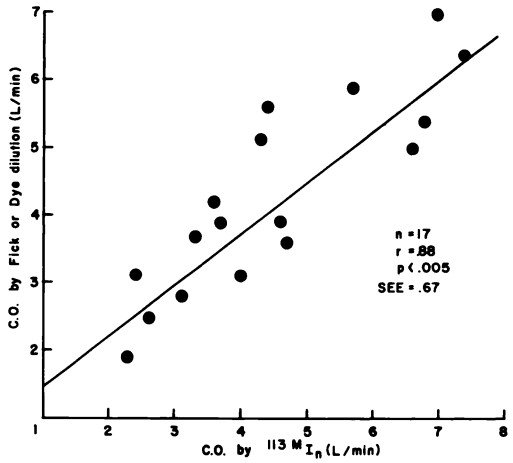

FIG. 4. Correlation of cardiac output determined from standard and radioisotope methods. CO, cardiac output; SEE, standard error of estimate; and r, correlation coefficient.

did not alter this correlation. The results of end-diastolic volume using the radioisotope method (stroke volume divided by ejection fraction) did not correlate as well with the results obtained by contrast cineangiography (r = 0.51). If patients with valvular regurgitation are excluded, however, this correlation was improved to 0.88 (Fig. 5).

DISCUSSION

Previous studies have shown that the left ventricular ejection fraction is a good measure of overall pump function (*1*) and of significant prognostic value in patients with coronary artery and valvular heart disease (*9,10*). Contrast cineangiographic methods used to determine the ejection fraction, although generally accepted as the most reliable standard for comparison, have certain inherent risks (*11*), can alter cardiac hemodynamics (*12*), and are not easily repeatable. The determination of cardiac output by standard Fick and dye dilution techniques involves cardiac catheterization. Therefore, a simple and safe method for repeated bedside measurements of left ventricular ejection fraction and cardiac output would be of great value in evaluating and managing patients with various forms of heart disease. The radionuclide method described in this communication requires only a central venous pressure line, uses simple equipment, is associated with minimal radiation exposure, and gives quick and accurate information on the cardiac output and left ventricular ejection fraction. Although the radionuclide method of measuring cardiac output is ideally suited to patients with ischemic heart disease hospitalized in coronary care units, the accuracy was equally good for patients with or without valvular heart disease. Steele, et al have reported a correlation of 0.78 for cardiac output determinations using ^{133m}In and standard Indocyanine dye methods (*7*).

There are several limitations that must be considered in using the radionuclide method. Calculation of the ejection fraction in patients with atrial fibrillation is difficult and may give inaccurate information. Ejection fraction measurements below 15% are difficult to measure accurately because of small changes in counting rate from beat to beat. The quantitation of end-diastolic volume may be less accurate since this calculated result depends on the accuracy of two separate determinations: ejection fraction and cardiac output.

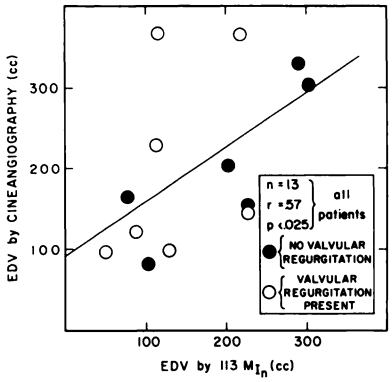

FIG. 5. Correlation of end-diastolic volume determined from cineangiographic and radioisotope methods when all patients are included. Comparison is not as close as for ejection fraction and cardiac output. EDV, end-diastolic volume; and r, correlation coefficient.

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REFERENCES

1. DODGE HT, BAXLEY WA: Hemodynamic aspects of heart failure. *Am J Cardiol* 22: 24–34, 1968

2. POMBO JF, TROY BL, RUSSELL RO: Left ventricular volumes and ejection fraction by echocardiography. *Circulation* 43: 480–490, 1971

3. GARRARD CL, WEISSLER AM, DODGE HT: The relationship of alterations in systolic time intervals to ejection fraction in patients with cardiac disease. *Circulation* 42: 455–462, 1970

4. DONATO L: Selective quantitative radiocardiography. *Prog Cardiovasc Dis* 5: 1–18, 1962

5. BURKE G, HALKO A, PESKIN G: Determination of cardiac output by radioisotope angiography and the image-intensifier scintillation camera. *J Nucl Med* 12: 112–116, 1971

6. VANDYKE D, ANGER HO, SULLIVAN RW, et al: Cardiac evaluation from radioisotope dynamics. *J Nucl Med* 13: 585–592, 1972

7. STEELE PP, VANDYKE D, TROW RS, et al: Simple and safe bedside method for serial measurement of left ventricular ejection fraction, cardiac output, and pulmonary blood volume. *Br Heart J* 36: 122–131, 1974

8. ALDERMAN EL, SANDLER H, BROOKER JZ, et al: Light-pen computer processing of video image for the determination of left ventricular volume. *Circulation* 47: 309–316, 1973

9. COLLINS JJ, COHN LH, SONNENBLICK EH, et al: Determinants of survival after coronary revascularization for angina pectoris. *Circulation* 46: Suppl II, 67, 1972

10. PORTER CM, BAXLEY WA, EDDLEMAN EE, et al: Left ventricular dimensions and dynamics of filling in patients with gallop heart sounds. *Am J Med* 50: 721–727, 1971

11. SWAN HJC: Complications associated with angiocardiography. *Circulation* 37 and 38: Suppl III, 81–84, 1968

12. GOOTMAN N, RUDOLPH AM, BUCKLEY NM: Effects of angiographic contrast media on cardiac function. *Am J Cardiol* 25: 59–65, 1970