

## Prompt return to normal of depressed right ventricular ejection fraction in acute inferior infarction<sup>1,2</sup>

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*A relatively simple, bedside, radionuclide technique has been developed to measure right ventricular ejection fraction. This technique uses a collimated scintillation probe (5 × 5 cm sodium iodide crystal) and <sup>113m</sup>Indium injected into the superior vena cava to record a right ventricular time-activity curve. The radionuclide method was validated in 34 men (14 normals, 20 with coronary artery disease) with biplane right ventriculography ( $r=0.82$ ). Using this radionuclide method right ventricular ejection fraction was measured in 26 men (average age 51 years) with an acute transmural myocardial infarction. Right ventricular ejection fraction was initially depressed ( $0.40 \pm 0.02$ ; mean  $\pm$  SEM; normal  $0.57 \pm 0.01$ ) in all of 11 men with an acute inferior infarction but returned to normal by the third day in 10 of them ( $0.58 \pm 0.01$ ; NS). In the 15 men with an acute anterior infarction the average right ventricular ejection fraction was normal initially ( $0.54 \pm 0.01$ ; NS) and individually 10 of 15 had a normal ejection fraction. Left ventricular ejection fraction was initially depressed in all patients and only 4 of 34 (12%) had returned to normal at the third day. These results suggest that right ventricular ejection fraction is regularly depressed in patients with an acute inferior infarction but normal in those with an anterior infarction. Right ventricular performance rapidly improves after inferior infarction; whereas less improvement occurs in left ventricular ejection fraction.*

Left ventricular ejection fraction has been found to be regularly depressed in acute myocardial infarction both early (Kostuk *et al.*, 1973) and late after infarction (Rackley *et al.*, 1970; Hamilton *et al.*, 1972; Stewart *et al.*, 1974). Kostuk and associates (1973) have shown that a relation exists between left ventricular ejection fraction and myocardial infarct size, as measured with serial determinations of serum creatine kinase activity. Though a disparity between right and left ventricular filling pressures in acute myocardial infarction has been appreciated (Forrester *et al.*, 1971) and infarction of the right ventricle has been recognised both clinically (Cohn *et al.*, 1974; Rotman *et al.*, 1974) and pathologically (Wartman and Hellerstein, 1948; Wade, 1959; Erhardt, 1974), relatively little attention has been paid to right ventricular performance in either chronic coronary

artery disease or acute myocardial infarction.

We had previously developed a radionuclide method for estimating left ventricular ejection fraction which uses a portable scintillation probe (Steele *et al.*, 1974). The purpose of the present study was to develop a radionuclide method for estimating right ventricular ejection fraction and to apply this technique to the serial study of patients with acute myocardial infarction.

### Subjects and methods

Right ventricular ejection fraction was measured from radiocardiograms obtained using a collimated scintillation probe by a modification of a radionuclide method for estimating left ventricular ejection fraction (Steele *et al.*, 1974). To measure right ventricular ejection fraction about 1 millicurie of <sup>113m</sup>Indium was injected into a catheter placed in the superior vena cava and flushed with saline. Using a scintillation probe (5 × 5 cm sodium iodide crystal) placed over the midpoint of

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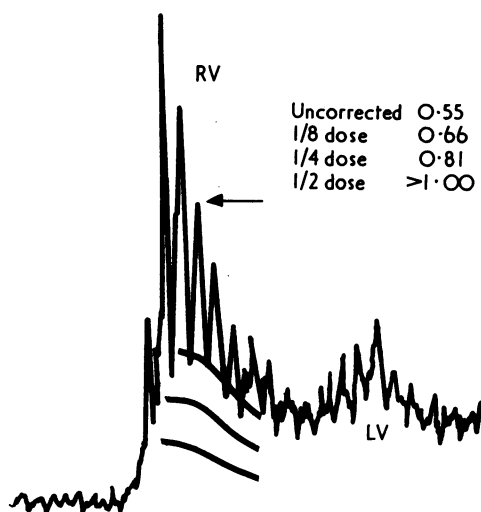


Fig. Time-activity curve recorded after injection of  $^{113m}\text{In}$  into the superior vena cava. The right ventricular (RV) and left ventricular (LV) portions of the curve are indicated. Using a shield (eclipse) collimation (see text) a series of curves was obtained for background correction; these are drawn under the right ventricular portion of the initial curve. Using the background curve (uppermost) obtained with half the initial dose of  $^{113m}\text{In}$  yields an ejection fraction of  $>1.00$  (average of 3 beats after end-diastolic point indicated by the arrow). The ejection fraction calculated using the curve (middle one) obtained with quarter the initial dose is also too high, while use of the curve (lowermost) obtained with eighth of the initial dose yields correct the ejection fraction (0.66) as judged from that computed using contrast cineventriculography.

the right ventricle in the anteroposterior projection, with the patient supine, a time-activity curve was recorded (Fig.). This curve was obtained with a ring collimator (3.5 cm port) as previously described (Steele *et al.*, 1974). After recording the right ventricular time-activity curve,  $\frac{1}{8}$  of the initial dose of  $^{113m}\text{In}$  was injected into the catheter and flushed and a second curve was obtained using a 5.5 cm circular shield collimator (Fig.). This second curve represents the count rate obtained from radionuclide-containing tissues which surround the right ventricle as the shield collimation rejects counts from the underlying right ventricle. Van Dyke and associates (1972) have indicated the need to correct a cardiac chamber time-activity curve for the effect of scattered radiation in order to measure the ejection fraction accurately (Van Dyke *et al.*, 1972).

To measure left ventricular ejection fraction, the same collimation was used but the probe was positioned over the midpoint of the left ventricle in the

anteroposterior projection with the patient supine. About 1 mCi  $^{113m}\text{In}$  was injected through the superior vena caval catheter and flushed with saline. A left ventricular time-activity curve was obtained and then a second curve was recorded with the shield collimation using half the initial dose of radionuclide. In these studies left ventricular ejection fractions were measured immediately after the right.

Accurate positioning of the probe was necessary to obtain a satisfactory record. The midpoints of the right and left ventricle were estimated from a supine anteroposterior chest film obtained just before the radionuclide study. Confirmation of correct probe position was obtained from the time-activity curve as each measurement of ejection fraction (beat to beat variation) should not differ by more than 10 per cent.

Ejection fraction was calculated as the fractional fall in count-rate from end-diastole to end-systole divided by the end-diastolic count rate. The correct baseline (corrected for scattered radiation) for measuring the end-diastolic count rate was obtained by matching the troughs of the 2 time-activity curves, port and shield, and drawing the shield record on the port recording (Fig.). Ejection fraction was calculated for as many beats as possible and averaged. This always included at least 2 beats for the right ventricle and 3 for the left ventricle.

In 34 men who underwent cardiac catheterisation and coronary arteriography for evaluation of chest pain, right ventricular ejection fraction was measured with the radionuclide method and from biplane (anteroposterior and steep left anterior oblique) contrast cineventriculograms using the area measurement method of Arcilla and associates (1971). Twenty men were found to have coronary artery disease and 14 had normal coronary arteriograms.

To derive the right ventricular ejection fraction from the ventriculograms, the outline of the right ventricle was traced from the projected end-diastolic (largest) and end-systolic (smallest) frames in both the anteroposterior (AP) and left anterior oblique (LAO) projections. The right ventricular volume (V) was calculated, using the planimetered areas of the anteroposterior and left anterior oblique projections with the maximum apex base dimension (L) in the LAO projection, as:

$$V = \pi L M_{\text{LAO}} \cdot M_{\text{AP}} / 6 \quad (1)$$

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

$$M_{\text{LAO}} = 4A_{\text{LAO}} / \pi L \quad (2)$$

and

$$M_{\text{AP}} = 4A_{\text{AP}} / \pi L \quad (3)$$

Using this method, Arcilla *et al.* (1971) noted good

correlation between contrast ventriculography and right ventricular casts.

In another group of 21 men without cardiac disease and with normal coronary arteriograms, left ventricular ejection fraction was measured with the scintillation probe and from single plane (right anterior oblique) contrast left cineventriculograms. The contrast ventriculograms were analysed using area length concepts (Dodge *et al.*, 1960; Kennedy *et al.*, 1970). The left ventricular silhouette was traced at end-diastole and end-systole and ejection fraction was computed as the difference between the end-diastolic and end-systolic volume divided by the end-diastolic volume, with volume (V) calculated as:

$$V = \pi LM^2/6 \quad (4)$$

where M was the minor axis in the right anterior oblique projection.

Serial radiograms were obtained from 26 men with an acute transmural infarction. These men ranged in age from 39 to 66 years (average 51 years) and had clinical and electrocardiographic evidence (Q waves in at least 3 leads) of acute anterior or inferior infarction of less than 24 hours duration. No patient had clinical or electrocardiographic evidence of previous myocardial infarction. All patients were studied at their bedside in the cardiac care unit as soon as possible after admission and initial stabilisation.

Radiocardiograms were recorded on the first, second, third, and twelfth day after infarction. All patients were in normal sinus rhythm and none had clinical evidence of mitral regurgitation. All patients were in Killip class I, II, or III (Killip, 1968) and none was in shock. Diuretics, digitalis, nitrates, or catecholamines were not administered at any time during their stay in hospital. All patients gave their informed consent for performance of these studies.

Eleven men had acute inferior infarction and 15 had acute anterior infarction. None had previous infarction and there were no differences between the two groups in age, Killip class, history of chronic obstructive airways disease, or systemic hypertension (Table). All patients survived to the

twelfth day, with 2 subsequent deaths in men with anterior infarction.

## Results

In the 14 normal men, right ventricular ejection fraction, estimated with the scintillation probe, averaged  $0.57 \pm 0.01$  ( $\pm$ SEM) with a range of 0.53 to 0.62. Using two standard deviations about the mean, the normal range was computed as 0.52 to 0.62. Right ventricular ejection fractions obtained in these 14 men from their ventriculograms had values with an average of  $0.58 \pm 0.63$ . In the 34 men, right ventricular ejection fraction was measured with the scintillation probe correlated ( $r=0.82$ ) with the right ventricular ejection fraction measured from contrast cineventriculography.

Left ventricular ejection fraction radiocardiographically measured in 21 normal men averaged 0.66 with a range of 0.57 to 0.77. Using two standard deviations the range of normal left ventricular ejection fraction was 0.56 to 0.76. The cineangiographic left ventricular ejection fraction in these 21 men averaged 0.66 and the range was 0.55 to 0.76. The left ventricular ejection fraction measured with the radionuclide method correlated with the left ventricular ejection fraction obtained from single plane cineangiography ( $M=0.91$ ;  $N=48$ ).

Serial radiocardiographic determinations of right and left ventricular ejection fraction (1–3 repeat studies in a 1–2 hour period) were undertaken in 12 men. Variation of average was always less than 10 per cent. Thus, the radionuclide method for estimating right and left ventricular ejection fractions seems to be accurate as measured against cineventriculography and to be reproducible.

The right ventricular ejection fraction was depressed ( $<0.52$ ) on the first day in all the men with acute inferior infarction and the average value  $\pm$ SEM was  $0.50 \pm 0.02$ ;  $P < 0.001$ . By the second day the average right ventricular ejection fraction was normal ( $0.53 \pm 0.01$ ) and 10 of the 11 patients had an increase in right ventricular ejection fraction of 0.05 or more. Some further increase was noted on the third day ( $0.58 \pm 0.01$ ) but there was no further change from day 3 to 12 ( $0.58 \pm 0.01$ ). At the third day only 1 patient had an abnormal right ventricular ejection fraction and this was only barely abnormal at 0.51. On the twelfth day all patients had a normal right ventricular ejection fraction.

In the men with acute anterior infarction the average right ventricular ejection fraction on the first day was normal ( $0.54 \pm 0.01$ ) but in 5 of the 15 it was depressed. By the second day it averaged  $0.56 \pm 0.01$  and in 2 of the 5 where it was initially

Table Clinical comparison of men with inferior and anterior infarction

	Inferior infarction (N=11)	Anterior infarction (N=15)
Average patient age (y)	49	52
Killip Class III	2	3
Clinical evidence of chronic obstructive airways disease	2	1
History or clinical evidence of systemic arterial hypertension	3	2

depressed it was now normal. On the third day 2 of the 15 had a depressed right ventricular ejection fraction and the average was  $0.56 \pm 0.01$  which persisted to the twelfth day ( $0.56 \pm 0.01$ ). Thus, right ventricular ejection fraction was regularly depressed early after acute inferior infarction and promptly improved, while in acute anterior infarction the ejection fraction was less often decreased and failed to return to normal in some patients.

The average left ventricular ejection fraction for the 11 men with acute inferior infarction was depressed ( $0.44 \pm 0.02$  days;  $P < 0.001$ ) and individually all had a decreased left ventricular ejection fraction. Some improvement was noted with time, averaging  $0.50 \pm 0.01$  on the second,  $0.51 \pm 0.01$  on the third, and  $0.52 \pm 0.01$  on the twelfth day after infarction. Only 2 men had a return to normal of the left ventricular ejection fraction ( $>0.55$ ) on the twelfth day and only 1 of these on the third day.

After acute anterior infarction the left ventricular ejection fraction was depressed in all patients and averaged  $0.39 \pm 0.02$  ( $P < 0.001$ ) on day 1. Some increase in average ejection fraction was noted on day 2 ( $0.43 \pm 0.02$ ), day 3 ( $0.45 \pm 0.02$ ), and day 12 ( $0.46 \pm 0.02$ ), but only 2 patients had a normal left ventricular ejection fraction on day 12 and these 2 were also normal on the third day. Thus, left ventricular ejection fraction did not appear to have the same potential for prompt increase as right ventricular ejection fraction after acute myocardial infarction. The 2 men who subsequently died had distinct depression of their left ventricular ejection fraction (0.28, 0.33) and had no improvement during the 12 days that they were studied.

## Discussion

The radionuclide technique described in this report seems to measure right ventricular ejection fraction accurately. Time-activity curves of the right ventricle should accurately reflect changes in volume if the radionuclide is properly mixed within the chamber, as the volume estimated from the count rate does not depend on the geometry of the chamber. Injection of radionuclide into the superior vena cava should provide adequate mixing as another chamber, the right atrium, is traversed before entry of tracer into right ventricle. A number of contrast angiographic methods have been developed for estimating right ventricular volume which use several geometric models for the right ventricle (Arcilla *et al.*, 1971; Graham *et al.*, 1973; Ferlinz *et al.*, 1975). All have been shown to be relatively accurate when compared with casts of the right

ventricle. The advantages of the radionuclide technique presented in this report are its relative simplicity, portability, and applicability to serial study.

Right ventricular time-activity curves must be corrected for the effect of scattered radiation if they are to be used to estimate ejection fraction. Radiation scatter in tissues occurs and consequently the time-activity curve recorded from the right ventricle contains counts from tissues surrounding this chamber. Therefore, a second time-activity curve is recorded with the right ventricle shielded. This recording reflects counts from tissues which surround the right ventricle.

Using the scintillation probe method for measuring left ventricular ejection fraction, with injection of radionuclide into the superior vena cava such that it traverses the pulmonary circulation, one-half of the initial dose of  $^{113m}\text{In}$  was used with the second injection (shield or eclipse tracing) to correct for scattered radiation. In the case of the right ventricle, one-eighth of the initial dose was found to provide the best estimate for calculation of ejection fraction (Fig.) The apparent lessened contribution of radiation scatter to the right ventricular time-activity curve as compared with the left ventricular curve probably reflects the absence of radionuclide within the pulmonary vasculature.

In our patients with acute inferior infarction all had an early decrease in right ventricular ejection fraction with a prompt improvement by the second day after infarction in 10 of 11 men. By the third day after infarction the right ventricular ejection fraction was normal in all but one patient. In another group of men with chronic coronary artery disease we found right ventricular ejection fraction to be normal in 22 of 29 (76%) patients with a history of inferior infarction, and 4 of the 7 with depressed right ventricular ejection fraction had triple vessel coronary artery disease on coronary arteriography (Steele *et al.*, 1976). In men with acute anterior infarction, right ventricular performance was generally preserved.

The blood supply of the right ventricle is usually derived from the right coronary artery. It is, therefore, not surprising that right ventricular performance is compromised in acute inferior infarction. It is of interest, however, how rapidly right ventricular ejection fraction improves. It is not certain which of several possible factors are responsible for this prompt improvement in performance. The right ventricular myocardium receives blood both during systole and diastole, whereas the left ventricular myocardium receives flow only during diastole (Wearn, 1941; Marshall and Shepherd, 1968). In addition the right ventricle can receive flow directly

through the thebesian vessels and collateral coronary blood flow is more extensively developed for the right than the left ventricle (Zaus and Kearns, 1952).

Rigo and associates (1975) found increases of right ventricular end-diastolic volume early after infarction in patients with acute inferior infarction and a normal right ventricular end-diastolic volume in patients with an acute anterior infarction. Of 14 patients with inferior infarction, 6 had an increased end-diastolic volume. These investigators used an electrocardiographically gated radionuclide technique.

Of additional interest, though of no particular surprise, is the fact that left ventricular ejection was decreased in all of our patients with acute infarction. Some early improvement in left ventricular ejection fraction was noted, but not nearly as strikingly as for the right ventricle. Kostuk and associates have performed serial measurement of left ventricular ejection fraction in 55 patients with acute infarction and noted improvement in ejection fraction in 30 (Kostuk *et al.*, 1973).

As discussed by Cohn *et al.* (1974) and Rigo *et al.* (1975) appreciation of the fact that right ventricular dysfunction might contribute to hypotension and shock after acute infarction is an important consideration in the management of these patients. The opportunity to assess right ventricular function at the bedside of these patients using the relatively simple radionuclide technique of Rigo *et al.* (1975) or the scintillation probe method discussed in this report should usefully complement their haemodynamic assessment.

## References

- Arcilla, R. A., Tsai, P., Thilenius, O., and Ranniger, L. (1971). Angiographic method for volume estimation of right and left ventricles. *Chest*, **60**, 446-454.
- Cohn, J. N., Guiha, N. H., Broder, M. I., and Limas, C. J. (1974). Right ventricular infarction. Clinical and hemodynamic features. *American Journal of Cardiology*, **33**, 209-214.
- Dodge, H. T., Sandler, H., Ballew, D. W., and Lord, J. D., Jr. (1960). The use of biplane angiocardiology for the measurement of left ventricular volume in man. *American Heart Journal*, **60**, 762-776.
- Erhardt, L. R. (1974). Clinical and pathological observations in different types of acute myocardial infarction. *Acta Medica Scandinavica*, Suppl. 560.
- Ferlinz, J., Gorlin, R., Cohn, P. F., and Herman, M. V. (1975). Right ventricular performance in patients with coronary artery disease. *Circulation*, **52**, 608-615.
- Forrester, J. S., Diamond, G., McHugh, T. J., and Swan, H. J. C. (1971). Filling pressures in the right and left sides of the heart in acute myocardial infarction. A reappraisal of central-venous-pressure monitoring. *New England Journal of Medicine*, **285**, 190-193.
- Graham, T. P., Jr., Jarmakani, J. M., Atwood, G. F., and Canent, R. V., Jr. (1973). Right ventricular volume determinations in children. Normal values and observations with volume or pressure overload. *Circulation*, **47**, 144-153.
- Hamilton, G. W., Murray, J. A., and Kennedy, J. W. (1972). Quantitative angiocardiology in ischemic heart disease: the spectrum of abnormal left ventricular function and the role of abnormally contracting segments. *Circulation*, **45**, 1065-1080.
- Kennedy, J. W., Trenholme, S. E., and Kasser, I. S. (1970). Left ventricular volume and mass from single-plane cineangiocardiology. A comparison of anteroposterior and right anterior oblique methods. *American Heart Journal*, **80**, 343-352.
- Killip, T. (1968). Coronary care units, current policies and results. In *Acute Myocardial Infarction*, p. 23, Ed. by D. G. Julian and M. F. Oliver. Williams and Wilkins, Baltimore.
- Kostuk, W. J., Ehsani, A. A., Karliner, J. S., Ashburn, W. L., Peterson, K. L., Ross, J., Jr., and Sobel, B. E. (1973). Left ventricular performance after myocardial infarction assessed by radioisotope angiocardiology. *Circulation*, **47**, 242-249.
- Marshall, R. J., and Shepherd, J. T. (1968). *Cardiac Function in Health and Disease*, p. 186. W. B. Saunders, Philadelphia.
- Rackley, C. E., Dear, H. D., Baxley, W. A., Jones, W. B., and Dodge, H. T. (1970). Left ventricular chamber volume, mass and function in severe coronary artery disease. *Circulation*, **41**, 605-613.
- Rigo, P., Murray, M., Taylor, D. R., Weisfeldt, M. L., Kelly, D. T., Strauss, H. W., and Pitt, B. (1975). Right ventricular dysfunction detected by gated scintiphotography in patients with acute inferior myocardial infarction. *Circulation*, **52**, 268-274.
- Rotman, M., Ratliff, N. B., and Hawley, J. (1974). Right ventricular infarction: a haemodynamic diagnosis. *British Heart Journal*, **36**, 941-944.
- Steele, P., Kirch, D., LeFree, M., and Battock, D. (1976). Measurement of right and left ventricular ejection fractions by radionuclide angiocardiology in coronary artery disease. *Chest*, **70**, 51-56.
- Steele, P. P., Van Dyke, D., Trow, R. S., Anger, H. O., and Davies, H. (1974). Simple and safe bedside method for serial measurement of left ventricular ejection fraction, cardiac output and pulmonary blood volume. *British Heart Journal*, **36**, 122-131.
- Stewart, D. K., Hamilton, G. W., Murray, J. A., and Kennedy, J. W. (1974). Left ventricular function and coronary artery anatomy before and after myocardial infarction. A study of six cases. *Circulation*, **49**, 47-54.
- Van Dyke, D., Anger, H. O., Sullivan, R. W., Vetter, W. R., Yano, Y., and Parker, H. G. (1972). Cardiac evaluation from radioisotope dynamics. *Journal of Nuclear Medicine*, **13**, 585-592.
- Wade, W. G. (1959). The pathogenesis of infarction of the right ventricle. *British Heart Journal*, **21**, 545-554.
- Wartman, W. B., and Hellerstein, H. K. (1948). The incidence of heart disease in 2,000 consecutive autopsies. *Annals of Internal Medicine*, **28**, 41-65.
- Wearn, J. T. (1941). Morphological and functional alterations of the coronary circulation. *Bulletin of the New York Academy of Medicine*, **17**, 754-777.
- Zaus, E. A., and Kearns, W. M. (1952). Massive infarction of the right ventricle and atrium. Report of a case. *Circulation*, **6**, 593-598.

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