Are right and left ventricular ejection fractions equal?

Ejection fractions in normal subjects and in patients with first acute myocardial infarction

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ABSTRACT Right and left ventricular ejection fractions (RVEF and LVEF) were determined by radionuclide imaging in 37 normal subjects and 37 patients by means of (1) the traditional way of calculating ejection fraction from first-pass time-activity curves of each ventricle generated from a single fixed ventricular region of interest, (2) dual first-pass time-activity curves generated from the end-diastolic and end-systolic regions, respectively, and (3) the multigated equilibrium method, also applying separate regions in end-diastole and end-systole for each ventricle. Values for RVEF measured by method 2 were significantly higher than values obtained by methods 1 and 3. In normal subjects, the values for RVEF measured by method 2 were equal to the values for LVEF determined by either this method or the equilibrium technique. Methods 1 and 3 had a tendency for underestimation of RVEF, probably because of inclusion of right atrial activity into the right ventricular region of interest. Methods 2 and 3 were applied to measure RVEF and LVEF, respectively, in 153 patients in the second week after first acute myocardial infarction. Among these, 25% had normal ejection fractions, 47% had a decrease in only LVEF, 8% a decrease in only RVEF, and 20% a decrease in both RVEF and LVEF. Circulation 72, No. 3, 502-514, 1985.

In a recent textbook of cardiovascular medicine, it is stated that "in man, the end-diastolic volumes of the two ventricles are approximately equal, and therefore the ejection fractions of the two ventricles are normally similar as well."

In the literature, however, the matter seems not quite settled, since some investigators have reported equal or nearly equal size of the ventricular volumes, whereas the majority of recent reports support the view that the right ventricle is larger than the left.

With the last years' increasing interest in the function of both ventricles and their interdependence, it has become relevant to have access to methods — preferably noninvasive — that can reliably quantify right and left ventricular function. Because of different chamber geometry and pattern of contraction of the two ventricles, dedicated methods of analysis should be applied to describe their function. Using radionuclide techniques, we have compared traditional with more elaborate, and in our opinion conceptually more correct, methods of analysis for calculation of right and left ventricular ejection fraction (RVEF and LVEF) in healthy human subjects and in patients with cardiac disease. Applying the same elaborate methods, we have also examined the incidence of abnormal values for RVEF and LVEF in a group of patients with first acute myocardial infarction (AMI).

Methods

The study population comprised three groups. Groups I and II, including 37 healthy and 37 diseased subjects, respectively, were investigated to compare three different radionuclide methods for determination of RVEF and LVEF: (1) the first-pass fixed area (fpFA) method, (2) the first-pass separate areas (fpSA) method, and (3) the multigated equilibrium (muga) approach. (These methods are described in detail below.) To examine the interobserver variation, two independent observers calculated "blindly," by means of the three methods of radionuclide analysis, six ejection fraction values in each of the 74 subjects: three values for RVEF (RVEFfpFA, RVEFfpSA, RVEFmuga) and three values for LVEF (LVEFfpFA, LVEFfpSA, LVEFmuga).
PATHOPHYSIOLOGY AND NATURAL HISTORY—VENTRICULAR FUNCTION

RVEF$_{maga}$ and three values for LVEF (LVEF$_{fpFA}$, LVEF$_{fpSA}$, LVEF$_{maga}$).

In group III, comprising 153 patients with first AMI, RVEF and LVEF were determined only once by a single observer using the fpSA method for calculation of RVEF and the muga technique to determine LVEF.

All subjects investigated were in stable sinus rhythm as required for multigated radionuclide imaging. Details concerning the three groups were as follows:

**Group I:** Thirty-seven healthy volunteers, 14 women (mean age 38 years, range 29 to 50) and 23 men (mean age 38 years, range 25 to 66), gave informed consent to participate in this part of the study, which was approved by the regional Scientific-Ethical Committee. All had a history without cardiopulmonary diseases and all had normal findings on physical examination, electrocardiogram and chest roentgenogram.

**Group II.** To compare the interobserver variation in normal and diseased subjects, 37 radionuclide studies from 37 patients were selected so as to cover a wide range of values for RVEF. There were 10 women (mean age 64 years, range 47 to 81) and 27 men (mean age 57 years, range 40 to 78). Their diagnoses were AMI (n = 29), heart failure caused by ischemic heart disease and/or previous myocardial infarction (n = 5), cardiomyopathy (n = 2), and endocarditis (n = 1).

**Group III.** This group included 153 consecutive patients fulfilling the following criteria: (1) first myocardial infarction, (2) hospitalization within 24 hr after the onset of symptoms, and (3) radionuclide examination carried out in the second week (eight to fifteenth day inclusive) after the onset. There were 38 women (mean age 65 years, range 45 to 81) and 115 men (mean age 58 years, range 35 to 78).

The diagnosis of AMI was based on previously described criteria, defined by the occurrence of a temporary, significant rise (>30 U/liter) in serum creatine kinase (CK)-MB levels in patients presenting with symptoms and/or electrocardiographic changes indicative of this disease. In five patients with maximal CK-MB levels between 18 and 30 U/liter the diagnosis was sustained by positive myocardial scintigraphic results with $^{99m}$Tc-pyrophosphate. (Scintigraphy is the hospital routine procedure in patients with equivocal electrocardiographic changes and CK-MB levels between 15 and 60 U/liter.)

If the characteristic electrocardiographic changes (decreasing or disappearing R wave and/or increasing Q waves together with typical development of ST-T changes) occurred in the precordial leads, infarcts were classified as anterior. Posterior/inferior location meant appearance of the same changes in leads II and III and/or the reverse changes in precordial leads $V_{1-2}$. Cases in which characteristic electrocardiographic changes could not be detected, e.g., because of the presence of bundle branch block, were also included and considered indeterminate.

**Radionuclide imaging.** All investigations were performed with subjects in the resting supine position. Red blood cells were labeled by a modified in vivo/in vitro technique with methylene-diphosphonate (Oseltite, NEN) and 30 mCi $^{99m}$Tc. Approximately 5 ml of labeled blood was placed in a saline-filled nylon line connected to an indwelling plastic cannula, preferably in a right medial cubital vein. An initial first-pass study was performed in a standard 30 degree right anterior oblique (RAO) view after flushing with 20 ml of saline. Data were collected in list mode during continuous recording of the electrocardiogram for later dynamic and/or gated reframing (see below). Subsequently, gated equilibrium imaging was undertaken in a left anterior oblique (LAO) view, giving optimal separation of the left ventricle from other chambers of the heart. A total of 5 million counts were collected in a 64 × 64 word matrix, with 20 frames per RR interval, the acquisition lasting typically 6 to 8 min.

**Data processing**

**First-pass studies.**

**fpFA method.** After dynamic reframing (20 frames/sec, i.e., frame duration 50 msec), frames were added to create pictures of the right and left ventricles. Because the activity in the two ventricles will reach maximum successively, pictures of each can be obtained without disturbing overlap of the other ventricle, despite the definite anatomic overlap in this projection (RAO). The outlines of the ventricles were drawn manually with a joystick on each picture, and the respective time-activity curves were generated (figure 1). RVEF was determined without background correction as the mean of a few successive (typically 2 or 3) beats, starting with the beat at the top of the curve, with the formula EF = (end-diastolic counts − end-systolic counts)/end-diastolic counts. LVEF was determined similarly, but with correction for background activity with use of an area near the apex of the ventricle (figure 1) and normalization of this area to the area of the left ventricular region of interest.

**fpSA method.** From the curves generated from the right and left ventricular regions with method 1, the frame numbers representing diastole and systole could be read. The diastolic frames were added to make a composite end-diastolic picture (figure 2, A and E), and similarly, systolic frames were summed to create an end-systolic picture (figure 2, B and F). On these new pictures the outline of each ventricle was redrawn to generate the corresponding time-activity curves (figure 2, C and G). Subse-

![FIGURE 1](http://circ.ahajournals.org/)

**FIGURE 1.** Traditional method of calculating RVEF (A) and LVEF (B) from a first-pass study performed in the 30 degree RAO view (fpFA). For each ventricle only a single region of interest is drawn on a composite picture, often representing one or several seconds of acquisition to improve image quality. Time-activity curves from this fixed area are recorded and ejection fraction is calculated as the mean of a few successive beats — on the left side after proper background subtraction. The arrows denote the beats used for calculation in the examples chosen.
subsequently, ejection fraction was calculated from the peaks of the diastolic area-curve and the troughs of the systolic area-curve. A crescent-shaped region for background correction was drawn at the apex of the right and left ventricles.

Because this procedure is time-consuming and cumbersome and because the same data could be obtained more easily by gated reframing of appropriate sections of the original list mode sequence, we chose instead to reframe sections representing the right and left ventricular passage with 16 frames per RR interval. At an average heart rate of 75 beats/min this would result in a frame duration of 50 msec. The end-diastolic and end-systolic frames, typically frames 1 and 7, respectively, were identified, and separate diastolic and systolic ventricular regions of interest were drawn as above. Often, a few frames adjacent to the end-diastolic and end-systolic frames, e.g., frames 2 and 15 + 16 or frames 6 and 8, were added to improve the quality of the two images. The corresponding gerninate curves were generated, and the peak of the average diastolic area-curve and the troughs of the average systolic area-curve were used for calculation of ejection fraction (figure 2, D and H). Background correction by area normalization was carried out with use of a region near the apex of each ventricle (figure 2, F).

Because the quantitative information is essentially the same whether the list mode data are reframed in the dynamic or gated mode, the latter procedure was used throughout the entire investigation. (Slight differences between the two modes of reframing are mainly caused by variation in frame duration with the gated approach because of the different heart rates of the patients.)

Equilibrium studies. These were collected in 20 frames. RVEF_{maga} was determined manually after identification of the frames representing right ventricular end-diastole and end-systole (which, in accordance with early reports on this matter, \(^{24-26}\) were not always identical to those representing the same phases of left ventricular contraction). The outline of the ventricle was drawn with a joystick on the two frames, and RVEF was calculated from the background-corrected counts included in the two areas. An area with the same location as applied for correction of the left ventricular activity was drawn for background correction (see below).

LVEF_{maga} was determined by a semiautomated program for calculation of LVEF from operator-defined end-diastolic and background regions of interest. The latter was invariably placed in the inferolateral vicinity of the left ventricle, encompassing the pixels with lowest activity in the end-systolic frame. Whenever inaccuracies in the automated computer analysis were noted, the outline of the left ventricle was drawn manually in both end-diastole and end-systole. This method of determining the LVEF had previously been validated by comparison with cineangiographic measurements. \(^{27}\)

Statistical evaluation. Comparisons between sets of values for ejection fractions were carried out by correlation analysis, the paired t test, and Pratt’s nonparametric test for paired data. \(^{28}\) For these comparisons, we used either the mean of the values obtained by the two observers (i.e., in case there was no statistically significant difference between their values) or the single values obtained by the two observers (i.e., in case such a difference [indicated by + in table 1] was present). The Bonferroni method \(^{29}\) was used to decrease the chance of mistakenly declaring significance due to multiple comparisons.

In the patients with AMI, linear regression analyses were carried out according to the least-squares principle. \(^{30}\) Differences between values for the serum CK-MB concentration were tested for by the unpaired t test.

FIGURE 2. Calculation of RVEF (top panel) and LVEF (bottom panel) by fpSA. The outline of each ventricle is drawn in diastole (A and E) and systole (B and F) on pictures composed of selected diastolic and systolic frames, respectively (see text). For background correction, a systolic area along the apical border of the ventricles is used (only shown for the left ventricle [F]). Resulting dual dynamic time-activity curves are displayed in C and G. Ejection fractions are calculated with the peaks (↑) of the upper (diastolic area) curve and the troughs (↓) of the lower (systolic area) curve. In D and H are shown the corresponding average curves obtained when gated instead of dynamic reframing is used (20 frames/cycle used in these examples). Ejection fraction is calculated from the end-diastolic (EDC) and end-systolic counts (ESC).
Results

Comparison of the different methods of radionuclide analysis. Results obtained in the 37 normal subjects are shown in figure 3, and in table 1 with the values from the 37 patients.

In the normal subjects, women and men were comparable in age. We failed to identify any differences between values for ejection fraction recorded in the two sexes. The 95% confidence limits of normal, defined by the 2.5 and 97.5 percentiles, are given at the bottom of figure 3.

The following relationships were observed between the ejection fractions recorded with various methods of analysis.

**RVEF.** In the normal subjects, values obtained by the fpSA method were significantly higher (mean 18 ejection fraction units, range 0 to 46; p < .001) than values determined by the muga technique, which again were higher (mean 8 units, range −8 to 21; p < .001) than the values calculated by the fpFA method (figure 3).

In the 37 patients the fpSA values were also lying at a clearly higher level than the fpFA and muga values for RVEF, which were of similar size (p in both instances < .001) (table 1).

The interobserver variation, expressed by the co-

<table>
<thead>
<tr>
<th>Method</th>
<th>Ejection fraction</th>
<th>Correlation coefficient</th>
<th>Coefficient of variation (%)</th>
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<tbody>
<tr>
<td>Normals (n = 37)</td>
<td></td>
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<tr>
<td>RVEF&lt;sub&gt;fpA&lt;/sub&gt;</td>
<td>40 (29–53)</td>
<td>37 (27–53)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.88</td>
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<tr>
<td>LVEF&lt;sub&gt;fpA&lt;/sub&gt;</td>
<td>56 (48–70)</td>
<td>58 (45–75)&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>.78</td>
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<tr>
<td>RVEF&lt;sub&gt;fpA&lt;/sub&gt;</td>
<td>65 (54–75)</td>
<td>66 (54–79)</td>
<td>.85</td>
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<tr>
<td>LVEF&lt;sub&gt;fpA&lt;/sub&gt;</td>
<td>65 (51–77)</td>
<td>67 (53–79)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.88</td>
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<tr>
<td>RVEF&lt;sub&gt;muga&lt;/sub&gt;</td>
<td>47 (35–70)</td>
<td>46 (26–71)</td>
<td>.27</td>
</tr>
<tr>
<td>LVEF&lt;sub&gt;muga&lt;/sub&gt;</td>
<td>64 (53–79)</td>
<td>64 (52–79)</td>
<td>.91</td>
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</table>

Patients (n = 37)

<table>
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<tr>
<th>Method</th>
<th>Ejection fraction</th>
<th>Correlation coefficient</th>
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<tr>
<td>RVEF&lt;sub&gt;fpA&lt;/sub&gt;</td>
<td>38 (17–71)</td>
<td>38 (15–70)</td>
<td>.98</td>
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<tr>
<td>LVEF&lt;sub&gt;fpA&lt;/sub&gt;</td>
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<td>37 (15–78)&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>RVEF&lt;sub&gt;fpA&lt;/sub&gt;</td>
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<td>52 (18–85)&lt;sup&gt;b,c&lt;/sup&gt;</td>
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<td>39 (11–72)</td>
<td>.80</td>
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<tr>
<td>LVEF&lt;sub&gt;muga&lt;/sub&gt;</td>
<td>37 (13–74)</td>
<td>36 (12–77)</td>
<td>.99</td>
</tr>
</tbody>
</table>

<sup>a</sup>Values (mean and ranges) are given in "ejection fraction units" (0–100); i.e., an ejection fraction of 0.37 = 37.

<sup>b</sup>Denotes significant (p < .05) difference between A and B.

<sup>c</sup>Not significant after applying the Bonferroni correction for multiple comparisons.
efficient of variation, was somewhat lower with the fpSA (4% in normal subjects and 4% in patients) than with the fpFA method (7% and 6%) but was very much higher with the muga technique (18% and 19%) (table 1).

LVEF. In the normal subjects, ejection fractions obtained by the fpSA method were on average 9 units (range -6 to 24) higher (p < .001) than those recorded with the fpFA method, against only 2 units (range -5 to 9) higher (p < .001) than the values determined by the muga technique (table 1).

In the patients, the sets of values for LVEF obtained by the three different methods were at the same level (table 1).

The interobserver variation was slightly lower with the fpSA method (4% in normal subjects and 6% in patients) than with the fpFA method (6% and 7%) and approximately of the same size as with the muga technique (3% and 6%).

RVEF vs LVEF. Remarkable was the finding in normal subjects that the values for RVEF$_{fpSA}$, LVEF$_{fpSA}$, and LVEF$_{muga}$ were similar (figure 3), with no statistically significant differences between them, except for the slightly higher values for LVEF$_{fpSA}$ than for LVEF$_{muga}$ (mentioned above).

In each of the normal subjects the difference between RVEF$_{fpSA}$ and LVEF$_{fpSA}$ or LVEF$_{muga}$ was less than 10 units (RVEF - LVEF; mean 1 unit, range -9 to 9).

Comparisons between values for RVEF and LVEF in diseased subjects were not relevant for the purpose of method evaluation (but of course pertinent when studying the nature of disease, as done below in the patients with AMI).

The influence of background correction on RVEF$_{fpSA}$ values was studied in the 37 patients. With correction, RVEF was on an average 1 unit (range 0 to 3) higher than when background correction was omitted.

RVEF and LVEF in patients with first AMI. Corresponding values for RVEF$_{fpSA}$ and LVEF$_{muga}$ measured in normal subjects and in the 153 patients with AMI are plotted in figure 4. Values for RVEF and LVEF were not significantly different in women and men.

Infarct location was anterior in 80 patients (52%), posteroinferior in 64 patients (42%), both anterior and posteroinferior in four patients (3%), and indeterminate in five (3%). Thirty-eight patients (25%) had normal ejection fractions in both ventricles, 72 (47%) had a decrease in LVEF only, 13 (8%) a decrease in RVEF only, and 30 (20%) had a decrease in both RVEF and LVEF.

Of the patients with a decrease in LVEF only, 69% (50/72) had anterior infarction, whereas 85% (11/13) of those with an isolated decrease in RVEF had posteroinferior infarction. This difference was highly significant ($\chi^2$-test, p < .001). Patients with decreased ejection fraction in both ventricles had equally frequent anterior and posteroinferior infarction. Conversely, of the patients with an isolated anterior infarction, 20% (6/30) had a decrease in LVEF and only 20% (6/30) had a decrease in RVEF. Of those with posteroinferior

![FIGURE 4. Relationship between RVEF and LVEF in 37 normal subjects (A) and 153 patients with first AMI (B). The unbroken line in A is the line of identity; the broken lines indicate the 95% confidence limits. The various symbols in B indicate the infarct locations.](http://circ.ahajournals.org/)}
in infarction, 39% (25/64) had a decrease in RVEF and 48% (31/64) had a decrease in LVEF.

The serum concentrations of CK-MB were significantly lower in patients with normal ejection fractions (mean 138 U/liter, range 18 to 428) than in patients with a decreased ejection fraction (p for all comparisons < .005). CK-MB levels were about the same whether there was a decrease in RVEF only (mean 262 U/liter, range 53 to 413), LVEF only (mean 251 U/liter, range 24 to 1090), or both (mean 285 U/liter, range 36 to 1381). There was a poor but significant inverse correlation between CK-MB levels and both RVEF (r = -.17; p < .05) and LVEF (r = -.28; p < .01).

Discussion

The occurrence of minor beat-to-beat fluctuations in stroke volume (and ejection fraction) is probably a normal phenomenon.31,32 Sudden disturbance of the function of one ventricle can induce transient divergencies (lasting a few cycles) between the stroke volumes of the two ventricles,26,33 but a state of balanced outputs must occur if systemic or pulmonary venous congestion is to be avoided.34 In the resting supine subject, the stroke volumes of the right (RV) and left ventricle (LV) must be practically identical, except in the presence of valve insufficiency or an intracardiac shunt. Since the ejection fraction is defined as stroke volume (SV) divided by end-diastolic volume (EDV), RVEF and LVEF are the same only if the end-diastolic volumes of the ventricles are equal:

\[ SV_{RV} = SV_{LV} = EF_{RV} \cdot EDV_{RV} = EF_{LV} \cdot EDV_{LV} \]

and hence

\[ EF_{RV} = \frac{EDV_{LV}}{EDV_{RV}} \]

Different methods based on various physical principles have been used to estimate ventricular volumes and ejection fractions. By means of an electric conductivity indicator dilution technique, Holt et al.35 measured the end-diastolic volume of both ventricles in nine species of mammals varying 1790-fold (rat to horse) in body weight. They found that the end-diastolic volumes of mammals were linear functions of body weight and not of body surface, an observation that was later confirmed by data reported in a cineangiographic study by Graham et al.3 Further, Holt et al.35 observed that the end-diastolic volume of the right ventricle was on average slightly smaller than that of the left when expressed in relation to body weight (right ventricular, 2.0 ml/kg; left ventricular 2.3 ml/kg), whereas the opposite was found when expressed in relation to body surface (right ventricular, 109 ml/m\(^2\); left ventricular, 93 ml/m\(^2\)). However, the most widely applied methods in man are the cineangiographic and the radionuclide techniques (tables 2 and 3).

Cineventriculography. Table 2 summarizes data from cineventriculographic studies in human beings.2-5,36-41 Although single-plane cineventriculography has been successfully used to measure right ventricular volume and ejection fraction,42 only studies applying the biplane technique have been included here. Even with the latter approach the geometric assumptions upon which the calculations rest might not always be fulfilled, especially not in the right ventricle with its complex and highly variable shape.36,38,43,44 Of the different principles of calculation, Simpson’s rule may provide the safest way of calculation, although it is difficult to ensure with these techniques that a measured length or diameter is obtained without distortion. Most of the studies cited in table 2 were carried out in children with normal hemodynamic findings on heart catheterization. With the exception of a single study,37 it was found that the end-diastolic volumes and the ejection fractions of the two ventricles were equal or nearly equal.

Radionuclide studies. Radionuclide techniques are widely used for noninvasive determination of both RVEF and LVEF. In the beginning, RVEF was measured only by first-pass techniques, but in recent years determination by gated equilibrium imaging has also been reported. Table 3 summarizes data from radionuclide investigations including values for RVEF obtained in either normal subjects or control patients.5-18,45-49

First-pass studies. With this approach the RAO view can be used to separate the right ventricle from the right atrium. The position of the tricuspid valve plane is shifted anteriorly and to the left during ventricular contraction. Therefore a fixed ventricular region of interest will not represent a reliable demarcation of the atrioventricular border in both diastole and systole (figure 5). Inclusion during systole of even a small portion of atrial activity within the ventricular region of interest will result in substantial underestimation of calculated RVEF because the atrium is in the process of being filled in this phase of the cardiac cycle. This tendency is particularly apparent in normal hearts and less pronounced in enlarged ventricles with poor contraction, because in the latter the change in ventricular size from diastole to systole is reduced and the
shift of the tricuspid valve plane relatively less marked (figure 5).

Fixed regions of interest have been used by most investigators (table 3), and RVEF has generally been found to be lower than LVEF in normal subjects with this method of analysis. Various kinds of background correction have been applied, resulting in different influence of atrial bias (overlap) on the calculated ejection fraction values. During the first passage of the radioactive bolus through the right ventricle there should be only negligible activity adjacent to it, except for the activity in the right atrium and the pulmonary artery. If proper delineation of the ventricle can be obtained in both diastole and systole, then background correction of the dual time-activity curves (figure 2, C and D) might well be unnecessary. In this respect, our study confirmed the findings of Winzelberg et al.,

who stressed the importance of using separate areas and found insignificant effect of background correction and normal values for RVEF in the same range, as we did.

Previously, we too have used the fpFa method for calculation of RVEF50 and found lower values for RVEF than for LVEF. However, visual inspection of gated equilibrium studies obtained in the same persons did not confirm that the right ventricle was bigger than

| Author, year       | No. of patients | Age (yr) | RVEDV ml | LVEDV ml | RVEDV ml | LVEDV ml | RVEF | LVEF | Comments
|--------------------|----------------|----------|-----------|-----------|-----------|-----------|------|------|----------
| Carlsson et al. 2   | 4             | 5-17     | 75        | 69        | 73        | 66        | 1.04 | 0.62 | 0.64 0.97 Values are calculated means of values given in table 1; AP and lateral views, modified Simpson's rule and two other methods
| Graham et al. 3     | 7             | < 1      | 11        | 39        | 11        | 39        | 1.01 | 0.66 | 0.63 1.04 Values from table 1. AP and lateral views. Simpson's rule and two-chamber method
| Gentzler et al. 6b  | 9             | Adults   | 81(63-101)|          |           |           | 0.51 |      | (0.40-0.66) Frontal and lateral views; Simpson's rule method; no LV data
| Thilenius et al. 37  | 9             | 2-10     | 78        | 66        | 1.18      | 0.61      | 0.74 | 0.82 | Values from table 2; frontal and lateral views; "parallelepiped method" of Arcilla et al. 21
| Ferlinz et al. 58   | 8             | 32-57    | 76(63-99) |           |           |           | 0.66 |      | (0.59-0.79) Values from table 1; RAO 30° and LAD 60° views; pyramid method; no LV data
| Fisher et al. 4     | 70            | 0.5-22   | 64        | 59        | 1.08      | 0.61      | 0.68 | 0.90 | Values from table 2; frontal and lateral views; Simpson's rule method
| Nakazawa et al. 5   | 40/87         | 0-16     | 16         | 75.1      | BSA 343   | 72.5      | BSA 343 | 1.02 | 0.61 0.63 0.97 Values from table 2; AP and lateral views; Simpson's rule method
| Lange et al. 29, 40  | 100           | 0-16     | BSA 429   | 73.1      | BSA 429   | 1.12      | 0.63 |      | 0.88 Values from table 5 in two successive articles; AP and lateral views; Simpson's rule method with corrections

RV = right ventricular; LV = left ventricular; EDV = end-diastolic volume; EF = ejection fraction; AP = anteroposterior; BSA = body surface area.

All listed figures were obtained in "normal" patients, i.e., control patients with normal hemodynamic findings.

The table numbers given refer to tables in the cited articles, not to tables in the present work.
the left; rather, the two ventricles appeared to be of equal size. This observation led to the elaboration of the fpSA method and the finding of equal RVEF and LVEF in normal subjects.

Values for LVEF calculated from the first-pass studies by either the fpFA or fpSA method differed less because the aortic valve plane is relatively fixed and because the left atrium interferes minimally in the RAO view. The slightly higher values for LVEF with the fpSA method than with the muga technique might be caused by differences in background correction. With the first-pass approach the background activity is coming mainly from the pulmonary vascular bed, varying with time. After equilibrium the activity from labeled blood cells in many different tissues contributes to the background activity in a much more complex fashion. "True" background cannot be determined accurately with either method.

Some investigators have proposed the use of stroke volume images to define the ventricular region of interest. In our experience, this also results in underestimation of RVEF because of the omission of diastolic ventricular activity near the tricuspid valve plane. Stroke volume counts in this area are counterbalanced and thereby abolished by atrial activity appearing in the same region during ventricular systole. This undesirable effect will be even greater if the anterior projection is used, since there is greater overlap between right atrium and right ventricle in this view. Subtraction of the activity in a narrow area in this transitional zone is an arbitrary way of solving the problem of overlap, resulting in higher but not necessarily correct RVEF values.

Multigated equilibrium studies. Maddahi et al. were the first to report determination of RVEF by gated equilibrium imaging. They recognized the problems with overlap between the right atrium and the right ventricle in the LAO view necessary for equilibrium studies and clearly demonstrated that if RVEF is calculated by means of a fixed diastolic region of interest, right atrial activity will become included in this region resulting in underestimation of RVEF. Using a procedure comparable to that of Maddahi et al., including the fpSA method, Winzelberg et al. and we found similar RVEF values in normal subjects by gated equilibrium imaging, but these values were substantially lower than those obtained by the fpFA method (table 3). In 20 patients, Maddahi et al. compared values for RVEF obtained by both gated first-pass and gated equilibrium imaging. They found a good agreement between the two methods, probably because they performed the first-pass studies in the anterior position with consequent overlap between the right atrium and the right ventricle and corresponding underestimation of RVEF.

Stroke volume images have also been used with the gated equilibrium principle in an attempt to overcome the problems in defining the right ventricular region of interest. However, the right atrium is often completely hidden behind the right ventricle in diastole and clear of it to an unknown degree in systole, depending on the size of both the ventricle and the atrium itself and on the individual degree of rotation of the heart. Under these circumstances it is therefore unclear what the stroke volume image represents.

Because of these reservations, we find it difficult to believe in the accuracy of the multigated equilibrium method for the determination of RVEF, even if separate areas are applied in diastole and systole. We would also be reluctant to measure relative changes in RVEF with this approach because of the poor reproducibility we have found in another investigation.

It seems that these problems with separation of right atrial and right ventricular activity have not been recognized as serious in most previous studies because comparisons were often made between values for RVEF measured by two different methods, each with their individual tendency for underestimation. Such comparisons may result in apparent agreement, especially if only diseased patients are investigated. The lower half of table 1 illustrates this. Except for the higher values for RVEF measured by the fpFA method, all other values seem to be almost equal with similar ranges. However, in the individual patients, RVEF (or LVEF) measured by either the fpFA method or the muga technique differed by up to 22 units in both directions. The reason for these divergences was clearly exposed in the first-pass studies from normal subjects, in whom the overlap between right atrium and right ventricle has a relatively greater influence on the size of the calculated ejection fraction (figure 5).

Conclusions on determination of RVEF. From a review of the literature and on the basis of our own results, we believe that reasonably accurate determinations of RVEF by radionuclide methods can be made only in an RAO view, in which right atrial and right ventricular activity can be reliably separated by first-pass techniques. Other projections will introduce overlap of right atrial and right ventricular activity, which cannot be properly corrected for. For this reason, muga equilibrium studies should not be used for determination of RVEF.

Our values for RVEF obtained in normal subjects by the fpSA method were similar to those measured by...
### TABLE 3
Data from articles concerning radionuclide determination of RVEF

<table>
<thead>
<tr>
<th>Author, year</th>
<th>Method(s)</th>
<th>Subjects</th>
<th>No. of patients</th>
<th>Age (yr)</th>
<th>RVEF</th>
<th>LVEF</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steele et al. (1976)</td>
<td>First pass</td>
<td>Controls</td>
<td>14</td>
<td>Adults</td>
<td>0.57(0.51-0.64)</td>
<td>0.66(0.57-0.74)</td>
<td>0.86 RAO 40°; slant hole collimator; Swan-Ganz catheter; “multiplied” background curve; fpFA method</td>
</tr>
<tr>
<td>Berger et al. (1978)</td>
<td>First pass</td>
<td>Normals</td>
<td>50</td>
<td>27-66</td>
<td>0.55(0.45-0.71)</td>
<td>0.69(0.58-0.70)</td>
<td>0.80 Anterior view, supine; background correction by area at tricuspid valve region; region of interest defined by stroke volume image; upper limit for LVEF a misprint?</td>
</tr>
<tr>
<td>Berger et al. (1979)</td>
<td>First pass</td>
<td>Controls &amp; normals</td>
<td>6</td>
<td>—</td>
<td>0.54</td>
<td>0.67</td>
<td>0.81 Same method as ref. 7; upright position</td>
</tr>
<tr>
<td>Berger et al. (1979)</td>
<td>First pass</td>
<td>Controls &amp; normals</td>
<td>8</td>
<td>—</td>
<td>0.55</td>
<td>0.67</td>
<td>0.82 Anterior view; upright position; same procedure as in refs. 7 and 8</td>
</tr>
<tr>
<td>Tobinick et al. (1978)</td>
<td>First pass</td>
<td>Normals</td>
<td>22</td>
<td>17-73</td>
<td>0.52(0.44-0.60)</td>
<td>0.60(0.52-0.73)</td>
<td>0.87 RAO 30°; background correction; fpFA method</td>
</tr>
<tr>
<td>Johnson et al. (1979)</td>
<td>First pass</td>
<td>Controls &amp; normals</td>
<td>3</td>
<td>25-69</td>
<td>0.47(0.43-0.55)</td>
<td>0.68(0.52-0.78)</td>
<td>0.69 Anterior view; same method as ref. 7</td>
</tr>
<tr>
<td>Maddahi et al. (1979)</td>
<td>Muga</td>
<td>Normals</td>
<td>15</td>
<td>28-66</td>
<td>0.48(0.39-0.57)</td>
<td>0.63(0.54-0.79)</td>
<td>0.76</td>
</tr>
<tr>
<td>Maddahi et al. (1980)</td>
<td>Muga</td>
<td>Controls &amp; normals</td>
<td>2</td>
<td>28-66</td>
<td>0.49(0.42-0.55)</td>
<td>—</td>
<td>— Same procedure as in ref. 11</td>
</tr>
<tr>
<td>Slutsky et al. (1980)</td>
<td>First pass (1)</td>
<td>Controls &amp; normals</td>
<td>5</td>
<td>24-52</td>
<td>(1.053)(0.46-0.83)</td>
<td>(2.049)(0.39-0.77)</td>
<td>0.87 RAO 30°, supine; fpFA method; same as ref. 46</td>
</tr>
<tr>
<td>Slutsky et al. (1980)</td>
<td>Muga (2)</td>
<td>Controls &amp; normals</td>
<td>15</td>
<td>—</td>
<td>(2.049)(0.39-0.77)</td>
<td>(2.049)(0.39-0.77)</td>
<td>0.80 (2) LAO 45°; supine; fixed area for right ventricular, variable for left ventricular</td>
</tr>
<tr>
<td>Holman et al. (1980)</td>
<td>Muga</td>
<td>Controls</td>
<td>11</td>
<td>—</td>
<td>0.59(0.49-0.74)</td>
<td>0.68(0.52-0.76)</td>
<td>Three different methods of calculating RVEF, all using fixed areas: LAO 35°-40°; slant-hole collimator; background region along right side of heart</td>
</tr>
</tbody>
</table>

**RV** = right ventricular; **LV** = left ventricular; **EF** = ejection fraction.

\(^1\)The listed figures were obtained in either control patients (controls), i.e., patients with normal hemodynamic findings, or in healthy individuals (normals). Ejection fractions are mean values with ranges in parentheses.

\(^2\)The table numbers given refer to tables in the cited articles, not to tables in the present work.
Winzelberg et al.⁶ by the same methods as well as those in the majority of the previous studies applying biplane cineangiography (table 2). On this basis, it seems fair to assume that the end-diastolic volume of the right ventricle in normal subjects is close to that of the left ventricle and that RVEF under normal conditions is approximately the same as LVEF with only small individual differences between them.

**Ejection fractions in patients with AMI.** Many have measured LVEF by radionuclide imaging in the initial stages of AMI¹⁴, ⁵²-⁵⁸ or within the first days.⁴⁶, ⁵⁹ Some have done it serially,⁶⁰-⁶⁴ others at the time of hospital discharge⁶⁵-⁶⁸ or during the ensuing months,⁶⁹ sometimes in combination with submaximal exercise testing.⁶⁵-⁶⁷, ⁶⁹-⁷¹ Several have also measured RVEF in these patients,¹⁴, ⁴⁶, ⁶², ⁶⁴, ⁷²-⁷⁷ either serially, ⁶², ⁶⁴ or more often in the initial stage and on a later occasion.¹⁴, ⁵⁶, ⁷³, ⁷⁴, ⁷⁷

To our knowledge, our study population comprises the largest reported number of patients with first AMI
in whom both RVEF and LVEF have been systematically measured. Radionuclide investigations were performed in the second week after infarction, at a time when the clinical condition of most patients was relatively stable. The prognostic significance of the combined determination of RVEF and LVEF in these patients will be dealt with separately.

Applying our method of measuring RVEF together with determination of LVEF by current radionuclide principles, we found that about one-fourth of the patients had entirely normal ejection fractions. Almost one-half had a decreased LVEF with a normal RVEF, less than one-tenth had a decrease in RVEF only, and one-fifth had a decrease in both ejection fractions.

**Clinical implications.** If RVEF and LVEF are almost equal in normal subjects, divergences between them (e.g., exceeding 10 units or more) might be an indication of beginning cardiac disease, even if both RVEF and LVEF are within the normal limits. This might be worth studying in patients with chronic pulmonary disease, in whom early depression of right ventricular function may be difficult to reveal. Berger et al.7 found, by their (rather) arbitrary first-pass method, depressed RVEF in a substantial number of patients with chronic obstructive pulmonary disease, even in those who did not present with any clinical symptoms of cor pulmonale. Furthermore, they demonstrated abnormal right ventricular reserve during exercise in patients with normal RVEF at rest.8 In contrast to this, Pop et al.9 could not demonstrate decreased RVEF in any patients unless they had clinical signs of either compensated or decompensated cor pulmonale.

In patients with AMI, measurement of both RVEF and LVEF may be clinically relevant, not only because this may reveal involvement of both ventricles, but also because it might aid in characterizing certain subgroups with prognostic and/or clinical implications.

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Are right and left ventricular ejection fractions equal? Ejection fractions in normal subjects and in patients with first acute myocardial infarction.

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