Right Ventricular Function in Aortic and Mitral Valve Disease*

Relation of Gated First-pass Radionuclide Angiography to Clinical and Hemodynamic Findings


Radionuclide ventriculography of the right heart was performed in 56 patients within two weeks of cardiac catheterization using a gated first-pass technique. Thirteen patients served as normal controls, and 43 patients had severe aortic or mitral valve disease or both, 35 of whom subsequently underwent valve surgery. Right ventricular ejection fraction (RVEF) and the presence of central venous reflux were determined and related to catheterization findings. In normal patients, RVEF was 60 ± 7 percent (mean ± 1 SD). In patients with valvular disease, the RVEF was below the normal range in only 2/14 (14 percent) when right ventricular peak systolic pressures were less than 50 mm Hg, compared with 16/29 (55 percent) with an RVEF below normal when right ventricular peak systolic pressures greater than 50 mm Hg (P < .05). In contrast, there was no relation of right ventricular ejection fraction to ventricular filling pressure in valvular heart disease patients. There was no difference in early postoperative course in patients with normal or reduced ejection fraction. Central venous systolic reflux was not present in normal patients, but was present in 3/12 (25 percent) and 22/25 (88 percent); P < .01) of patients with right ventricular systolic pressures below and above 50 mm Hg, respectively, including all ten patients with documented tricuspid regurgitation. Radionuclide assessment of right ventricular function in patients with aortic or mitral valve disease or both provides information that cannot be inferred from right-sided pressure measurements.

In severe left-sided valvular heart disease, elevated left atrial and pulmonary artery pressures produce a severe pressure overload on the right heart, which may result in right ventricular failure and functional tricuspid regurgitation.1-4 Evaluation of severe left-sided valvular heart disease includes a determination of right heart function, usually by hemodynamic measurements. New radionuclide techniques have also been suggested as a means of noninvasively determining right ventricular function.5-12

In this study, right heart function in patients with left-sided valvular heart disease was assessed using gated first-pass radionuclide angiography, and the radionuclide data were related to both clinical and catheterization findings. In particular, this study sought answers to the following questions: (1) What is the relation of right ventricular ejection fraction (RVEF) to both the severity of the pressure overload on the right ventricle in valvular heart disease (ie, right ventricular peak systolic pressure) and to right ventricular filling pressure (ie, right atrial pressure)? (2) Does the RVEF have prognostic value in patients undergoing valve surgery? and (3) What is the significance of reflux of tracer into central venous channels?

**METHODS**

**Patient Population**

Fifty-six adult patients were studied at rest by radionuclide angiography within two weeks of diagnostic right- and left-heart catheterization. Thirteen patients referred for evaluation of chest pain or heart murmurs or both and having no hemodynamic or angiographic abnormalities were the control group. There were eight men and five women, with a mean age ±1 SD of 53 ± 13 years (range, 31 to 81 years). All were in normal sinus rhythm.

Forty-three patients with significant aortic or mitral valve disease or both comprised the study group. All pa-
tients had class 1 to 3 cardiac symptoms by New York Heart Association criteria, including 10 with aortic, 21 with mitral, and 12 with both aortic and mitral valve disease. They were not consecutive patients, in that patients with higher pulmonary artery pressures were preferentially included. There were 14 men and 29 women, with a mean age of 58 ± 8 years (range, 28 to 74 years). Twenty patients were in normal sinus rhythm, and 23 were in atrial fibrillation with a moderate ventricular response (<110 beats/min). Patients with differences in cycle length greater than 200 msec were excluded. Ten of these patients also had tricuspid regurgitation defined as follows: systolic V-waves in the jugular venous pulse; a holosystolic murmur that increased in intensity during inspiration; a pulsatile liver to palpation; and prominent C-V waves in the right atrial pressure recording. No patient had significant coronary artery disease.

Thirty-five of the 43 patients subsequently underwent open heart surgery to replace the aortic or mitral valve or both. Twenty patients underwent mitral valve replacement, six underwent aortic valve replacement, and nine underwent aortic and mitral valve replacement. Early postoperative course was assessed from total cardiopulmonary bypass time, aortic clamp–clamp time, length of time intubated, length of time in the hospital after surgery, and survival to hospital discharge.

Radionuclide Data Acquisition

Images were collected on a 25-cm field of view gamma camera (Ohio Nuclear series 420, Ohio Nuclear Inc, Solon, Ohio) equipped with a low-energy, parallel-hole, all-purpose collimator with a dedicated nuclear medicine computer system interface (Ohio Nuclear VIP 450). Pretreatment was given with stannous pyrophosphate (Pyrolite, New England Nuclear, North Billerica, Mass) 30 minutes before injection of 99m-technetium pertechnetate (99mTc) to achieve in vivo labeling of the red blood cells.1 Patients were then positioned supine, with the surface of the gamma camera placed in the 30° right anterior oblique position and the precordium centered in the field. Because the camera was on the right side of the patient for the first-pass study, the tracer was injected in the left arm. A blood pressure cuff was placed on the patient's left upper arm and inflated to a pressure 20 mm Hg beneath systolic arterial pressure. A 23-gauge, 2.54-cm needle was then placed in the median basilic vein. The cuff was further inflated to a pressure 50 mm Hg above systolic blood pressure for three minutes. Twenty mCi of 99mTc dissolved in less than 0.5 ml of normal saline solution was then injected directly into the 23-gauge needle. The left arm was then raised above the patient's head, and the blood pressure cuff abruptly removed.

Data acquisition for the gated first-pass study was manually started when the tracer was first seen to enter the superior vena cava on the persistence oscilloscope of the scintillation camera and terminated when activity first entered the lungs. In this way, the activity of 6 to 15 beats (mean, 9) was summed into a 16-frame collection gated to the ECG. All beats were included in the acquisition. Computer filtering of premature or delayed beats was not used. Data from individual beats (list mode acquisition) were not collected. Subsequently, equilibrium multigated cardiac blood pool scans were recorded at 32 frames per cardiac cycle using a standard technique.14 Both first-pass and equilibrium scans were collected in a 64 × 64 matrix.

**RVEF Analysis**

The radionuclide data were analyzed without knowledge of clinical or catheterization findings. The method of calculating RVEF is shown in Figure 1. A region of interest was established manually using a light pen, which encompassed the right ventricular cavity in the first frame (delimited by the tricuspid valve plane, right ventricular free wall, and pulmonary outflow tract superiorly). The counts within this region of interest in each of the 16 frames were determined to establish the end-diastolic (maximum activity) and end-systolic (minimum activity) frames. Regions of interest were then similarly manually placed over the right ventricle in the frames determined to be end-diastole and end-systole, and the ejection fraction was then calculated as a percentage from the formula

\[
\frac{EDC - ESC}{EDC} \times 100
\]

The mean ± 1 SD end-diastolic (EDC) and end-systolic (ESC) counts were 3,541 ± 1,922 and 1,807 ± 693, respectively. Each RVEF was calculated on three separate occasions by a single observer unaware of clinical and catheterization findings. The interval between each set of calculations was one month. The average of these numbers was used as the RVEF.

No background subtraction was performed, since activity was primarily in the right heart and not in the left heart or lungs. Evaluation of ten randomly selected patients from the test group showed extremely low background activity adjacent to the right ventricle (less than two counts per pixel). No significant difference in RVEF was found when background subtraction was omitted or in-

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*CHEST, 79: 5, MAY, 1981*

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[Figure 1. (Upper). End-diastolic image (left) and end-systolic image (right) from gated first-pass radionuclide study in a normal control patient. (Below). Placement of regions of interest for calculation of right ventricular ejection fraction, 60 percent in this patient.]
cluded in these patients.

The tracer was injected in such a way as to minimize bolus dispersion. However, because the RVEF calculation was based on summed end-diastolic and end-systolic counts and was not derived using indicator dilution principles, it did not depend on an intact tracer bolus. The purpose of the bolus injection was to maximize and isolate counts within the right heart before the arrival of activity in the lung and left heart. This allowed the 30° right anterior oblique view to be used, which maximizes separation of right atrium and right ventricle without inclusion of activity within the left ventricle. An alternative method of separating the right from the left ventricle is the use of the left anterior oblique view equilibrium scan, but this approach may be limited by telescoping of the right ventricle and overlap of the right atrium. To compare this alternative method with the first-pass gated method, RVEF was also derived in these patients from the left anterior oblique gated equilibrium scan using the method of Maddahi.11

Left Ventricular Ejection Fraction

The left ventricular ejection fraction was calculated from the left anterior oblique equilibrium gated scan.14–16 After an appropriate background area was selected and subtracted from each frame, the end-diastolic left ventricular perimeter was identified. The computer then generated the left ventricular border in each subsequent frame, using a 4-quadrant threshold program. A curve describing activity in the left ventricular region of interest in relation to the cardiac cycle was generated, and the ejection fraction calculated as the difference between maximum and minimum activity divided by maximum activity.

Evaluation of Reflux

The gated first-pass study through the right heart was cinematically displayed for definition of the right brachiocephalic vein, hepatic veins, superior and inferior vena cava, right atrium, right ventricle, pulmonary outflow tract, and pulmonary artery branches. Two observers unaware of clinical or catheterization findings examined the area above and below the region of the right atrium for tracer reflux. Reflux was considered present if activity was intermittently seen in the right brachiocephalic vein, hepatic veins, or the inferior vena cava during ventricular systole. The final decision was achieved by consensus.

Catheterization Procedure and Analysis

All patients with valvular heart disease underwent cardiac catheterization by the Sones or Judkins technique. This included measurement of pulmonary capillary wedge, pulmonary artery, right ventricular peak systolic (RVSP), and right atrial pressure as a measure of right ventricular filling pressure (RVFP), and cardiac output by the Fick method. Pulmonary arterial resistance was the difference between the mean pulmonary artery and mean pulmonary capillary wedge pressure divided by the cardiac index, expressed in units. Right ventricular contrast angiography was not performed. Patients were excluded if they had significant coronary artery disease (> 50 percent diameter luminal narrowing in one or more major vessels).

Statistical Analysis

Values for group data were expressed as mean ±1 SD, and mean differences were compared using a one-way analysis of variance. Frequency data were compared using χ² analysis. Intraobserver variability of the ejection fraction measurement by the first-pass method was determined using a two-way analysis of variance. Linear regression analysis was used to compare RVEF first pass values with RVEF equilibrium values. To determine the relationship of RVEF to right ventricular systolic pressure, the study patients were divided into those with right ventricular systolic pressure above and below 50 mm Hg and compared with each other and to the control patients. To determine the relationship of RVEF to RVFP, the study patients were divided into those with right atrial pressure above and equal to or below 5 mm Hg and compared with each other. To determine the relationship of RVEF to prognosis, the 35 patients undergoing valve replacement were divided into those with a normal or a reduced RVEF, and the early postoperative course in each group was compared. To determine the diagnostic value of central venous reflux, the hemodynamic and angiographic findings in study patients with and without reflux were compared.

RESULTS

Representative first-pass radionuclide angiograms are illustrated in a normal control patient (Fig 1) and in study patients (Fig 2 and 3). The right heart chambers are clearly outlined, with essentially no background. The brachiocephalic vein and superior vena cava appear more intense than the right atrium and right ventricle, reflecting the entry of unlabeled inferior vena cava blood into the right atrium.

![Figure 2. End-diastolic (left) and end-systolic (right) images of right heart in patient with severe aortic valve disease. Little difference in size of right ventricle in two images; calculated right ventricular ejection fraction, 33 percent. Right ventricular systolic pressure, 54 mm Hg; mean right atrial pressure, 18 mm Hg.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21219/)
Figure 3. Two systolic right heart images from patient with mitral valve disease and clinically evident tricuspid regurgitation: mid-systole (left) and end-systole (right). Reflux of tracer in right brachiocephalic vein in both, but more prominent at mid-systole. Right ventricular ejection fraction, 51 percent. Right ventricular systolic pressure 80 mm Hg; mean right atrial pressure, 12 mm Hg.

**Measurement of RVEF**

Linear regression analysis of the individual values of RVEF determined by a single observer at different points in time gave a correlation coefficient of 0.95 (P < 0.01), with a regression slope of 1.03 and a Y intercept of 1.4, which is nearly a line of identity. The intraobserver variance, expressed as ±1 SD, was 3 percent in absolute RVEF units. The RVEF by the equilibrium method was linearly related to that of the first-pass method (r = 0.61, P < .01). The values by equilibrium were lower in both normal, (46.8 ± 7.7 percent vs 60.0 ± 7.0 percent, P < .05) and in valve disease patients

**Table 1—Catheterization and Scan Findings in Relation to Right Ventricular Systolic Pressure**

<table>
<thead>
<tr>
<th>Valvular Disease Patients</th>
<th>RVSP &lt; 50</th>
<th>RVSP &gt; 50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Group (n = 14)</td>
<td>(n = 29)</td>
<td></td>
</tr>
<tr>
<td>RA pressure, mm Hg</td>
<td>2.6 ± 0.9</td>
<td>5.2 ± 3.7</td>
</tr>
<tr>
<td>PA systolic pressure, mm Hg</td>
<td>26.2 ± 3.9</td>
<td>35.4 ± 8.6†</td>
</tr>
<tr>
<td>PCW pressure, mm Hg</td>
<td>9.2 ± 4.0</td>
<td>15.5 ± 6.1†</td>
</tr>
<tr>
<td>PAR, units</td>
<td>2.3 ± 1.0</td>
<td>2.6 ± 1.6</td>
</tr>
<tr>
<td>RVEF, %</td>
<td>50.9 ± 7.0</td>
<td>51.4 ± 6.0†</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>62.0 ± 15.7</td>
<td>59.2 ± 17.1</td>
</tr>
</tbody>
</table>

†P < .05, compared with value for control group.
‡P < .05, compared with value for control group.

*LVEF = left ventricular ejection fraction; RA = right atrial; PA = pulmonary artery; PCW = pulmonary capillary wedge pressure; PAR = pulmonary arteriolar resistance; RVEF = right ventricular ejection fraction; RVSP = right ventricular systolic pressure. Values given are mean ± 1 SD.

(39 ± 8.0 percent vs 47.1 ± 9.3 percent; P < .05) than the first-pass values.

**Relationship of RVEF to RVSP**

Table 1 shows the catheterization and scan findings in control patients and in study patients with RVSPs above and below 50 mm Hg. Study patients with RVSPs above 50 mm Hg had higher pulmonary capillary wedge pressures, right atrial pressures, and pulmonary arteriolar resistances than both the study patients with RVSPs below 50 mm Hg and control patients (P < .05). A plot of individual RVEF values in all patients is shown in Figure 4. The RVEF in control patients was 60.0 ± 7.0 percent, with a normal range of 46 to 74 percent (± 2 SDs). Valvular heart disease patients with RVSPs below 50 mm Hg had a mean RVEF of 51.4 ± 6.0, which was lower than control patients (P < .05). Study patients with RVSPs above 50 mm Hg had a mean RVEF of 44.6 ± 10.9 percent, which was less than both normal subjects and patients with RVSPs below 50 mm Hg (P < .05).
Table 2—Comparative Catheterization and Scan Findings *

<table>
<thead>
<tr>
<th></th>
<th>Aortic Valve Disease</th>
<th>Aortic and Mitral Valve Disease</th>
<th>Mitral Valve Disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>10</td>
<td>12</td>
<td>21</td>
</tr>
<tr>
<td>RA pressure, mm Hg</td>
<td>6 ± 4</td>
<td>7 ± 3</td>
<td>9 ± 5†</td>
</tr>
<tr>
<td>PA systolic pressure, mm Hg</td>
<td>43 ± 11</td>
<td>62 ± 21</td>
<td>73 ± 30†</td>
</tr>
<tr>
<td>PCW pressure, mm Hg</td>
<td>17 ± 8</td>
<td>28 ± 9</td>
<td>28 ± 7†</td>
</tr>
<tr>
<td>PAR, units</td>
<td>4 ± 3</td>
<td>7 ± 5</td>
<td>7 ± 5</td>
</tr>
<tr>
<td>RVEF, %</td>
<td>45 ± 10</td>
<td>51 ± 11</td>
<td>46 ± 9</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>55 ± 14</td>
<td>57 ± 16</td>
<td>57 ± 16</td>
</tr>
</tbody>
</table>

* LVEF = left ventricular ejection fraction; PA = pulmonary artery; PAR = pulmonary arteriolar resistance; PCW = pulmonary capillary wedge; RA = right atrial; RVEF = right ventricular ejection fraction. Values are mean ± 1 SD.
† P < .05, compared to patients with aortic valve disease.

Among patients with RVSPs above 50 mm Hg, 13 (45 percent) maintained RVEF within the normal range. As a result, linear regression analysis showed no correlation between RVEF and RVSPs (r = 0.23).

Nine of the ten patients with clinically evident tricuspid regurgitation had RVSPs above 50 mm Hg. Nevertheless, the mean RVEF in these nine patients was not different from the mean RVEF in the 20 patients with > 50 mm Hg RVSP without clinically evident tricuspid regurgitation (42.3 ± 6.7 percent vs. 45.5 ± 4.3 percent). Mean left ventricular ejection fraction in valvular disease patients did not differ significantly from normal (Table 1) and was above 50 percent in 38 (88 percent) of the 43 study patients.

The catheterization and scan findings in the study patients for the different combinations of valve abnormalities are shown in Table 2. All patients had elevated right-sided pressures; however, the patients with mitral valve disease had a higher mean right atrial, pulmonary artery systolic, and pulmonary capillary wedge pressure than the patients with aortic valve disease (P < .05). The mean right ventricular and left ventricular ejection fractions did not differ in these groups.

Relationship of RVEF to RVFP

The individual values for RVEF in valvular heart disease patients in relation to RVFP is shown in Figure 5. Seventeen patients had right atrial pressures of 5 mm Hg or less, of whom seven (41 percent) had reduced RVEF. Twenty-six patients had right atrial pressures of 6 mm Hg or more, of whom eight (31 percent) had reduced RVEF. The difference was not statistically significant. The mean RVEF in each group was the same (47.1 percent vs 46.0 percent), and there was no linear relation between RVEF and RVFP (r = −0.17).

Nine of the ten patients with clinically evident tricuspid regurgitation had elevated right atrial pressures. Nevertheless, RVEF in these nine patients did not differ significantly from RVEF in patients with elevated right atrial pressures but without tricuspid regurgitation (42.3 ± 6.7 percent vs 47.9 ± 8.4 percent).

Relationship of RVEF to Early Postoperative Course

Among the 35 patients undergoing valve surgery, the early postoperative clinical course was compared in patients with normal RVEF (46 percent or above) and those with low RVEF (below 46 percent), shown in Table 3. Although more patients with a reduced RVEF were intubated more than three days and hospitalized more than 20 days, the difference was not significant. Two patients with normal RVEF and two with reduced RVEF died during or following surgery.

Tracer Reflux

Tracer reflux was not evident in any of the 13 normal subjects, but was observed in 25 of 37 study patients (68 percent). Of the 25 patients

* In six of the 43 study patients, the camera had not been properly centered before the injection of tracer to include both the right brachiocephalic vein and inferior vena cava within the field of view during the first-pass study. These six patients were excluded from the analysis of reflux.
TABLE 3—Early Postoperative Course in Relation to Right Ventricular Ejection Fraction

<table>
<thead>
<tr>
<th></th>
<th>RVEF*</th>
<th>RVEF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;46%</td>
<td>&gt;46%</td>
</tr>
<tr>
<td></td>
<td>(n=17)</td>
<td>(n=18)</td>
</tr>
<tr>
<td>Bypass time, min†</td>
<td>118.1 ± 66.1</td>
<td>105.1 ± 36.5</td>
</tr>
<tr>
<td>Cross-clamp time, min†</td>
<td>30.2 ± 7.3</td>
<td>25.4 ± 6.0</td>
</tr>
<tr>
<td>Duration of intubation &gt;3 days, No. (%)</td>
<td>3 (18)</td>
<td>7 (39)</td>
</tr>
<tr>
<td>Duration of hospitalization &gt;20 days, No. (%)</td>
<td>4 (24)</td>
<td>8 (44)</td>
</tr>
<tr>
<td>Survival to hospital discharge, No. (%)</td>
<td>15 (88)</td>
<td>16 (89)</td>
</tr>
</tbody>
</table>

*RVEF = right ventricular ejection fraction.
†Mean ± 1 SD.

with reflux, eight were in normal sinus rhythm, and 17 were in atrial fibrillation. All ten patients with clinically evident tricuspid regurgitation showed reflux. Tracer reflux was more frequent in patients with RVSP above 50 mm Hg (22/25; 88 percent) than in patients with RVSPs below 50 mm Hg (3/12, 25 percent; P < .01). Patients with valvular heart disease demonstrating venous reflux had significantly higher RVSPs and pulmonary arteriolar resistances (Table 3), but reflux could not be related to differences in right atrial pressure, RVEF, or left ventricular ejection fraction.

DISCUSSION

Evaluation of RV Function

Although it is well recognized that the right ventricle can be affected in patients with severe left-sided valvular heart disease, right ventricular contrast angiography is seldom performed in these patients for the following reasons: (1) the hyperosmolar contrast injection may be poorly tolerated as an added volume load to a patient who is already likely to have elevated left atrial pressures; (2) no widely accepted method for quantitating RVEF is available,† and (3) tricuspid regurgitation during right ventriculography may be catheter-induced. Radionuclide methods overcome these difficulties, and prior studies have shown the usefulness and reliability of these techniques.

The analysis of right ventricular function used in this study uses gated first-pass radionuclide angiography to obtain right ventriculography. Data were obtained solely from the initial passage of tracer through the right heart, avoiding overlap of the left atrium and left ventricle. The right anterior oblique projection was used to optimize separation of the right atrium from the right ventricle. The ability of this method to isolate the right ventricle, avoiding overlap of any cardiac chamber, is its primary advantage over an analysis of right ventricular function from the left anterior oblique-view, gated equilibrium scan. Right ventricular ejection fraction may also be calculated from the left anterior oblique equilibrium scan, but the values for RVEF appear to be lower. This is in part a result of overlap of right atrial activity. Such distortion may become a particular problem in disorders in which the atria are enlarged.

The first-pass method sums data from each cycle during the passage of the tracer from the superior vena cava through the right heart to the lungs. Because activity from successive cardiac cycles is summed, and because data from individual beats are not acquired separately, the data remain useful if there is some dispersion of the tracer bolus during the first pass, as might occur with tricuspid regurgitation. In atrial fibrillation, with large variations in ECG cycle length, there may be profound beat-to-beat differences in the duration of diastole, end-systolic volume, stroke volume, and ejection fraction. The ability of a gated-scan-derived ejection fraction to measure reliably the "mean" ejection fraction of individual beats in atrial fibrillation has not been demonstrated. Nevertheless, the variation in cycle length in atrial fibrillation changes the duration and timing of systole minimally; therefore, the gated acquisition is likely to represent the systolic contraction of a hypothetical average cardiac cycle. In this study, patients with large variations in cycle length were excluded to minimize beat-to-beat differences in ejection fraction. Another approach would be using a computer to filter data from exceedingly short or long R-R intervals, but this was not available in this study.

During the first pass, activity in the right ventricle is proportional to its volume, and the change in activity in the right ventricle from end-diastole to end-systole reflects stroke volume independent of geometry. Therefore, the change in activity during systole divided by end-diastole activity represents the ejection fraction. Since background activity in the first-pass gated study was very low, no background subtraction was used, although prior first-pass studies have used a background subtraction. The image quality allowed the right ventricular borders to be readily and reproducibly defined, as evidenced by the low intra-observed variance for ejection fraction (3 percent). In addition, the normal range of RVEF values (46 to 74 percent) obtained by the gated first-pass method compares favorably with that found by
other radionuclide\textsuperscript{10-12} and contrast angiographic\textsuperscript{17,19,31} determinations. Nevertheless, the values derived using the first-pass approach appear to be higher than those derived using the equilibrium approach. The first-pass values may be artifactualy increased by streaming and incomplete mixing of the tracer within the right ventricle, whereas the equilibrium values may be artifactualy lowered by inclusion of overlapping right atrial activity in the ventricular volume curve.\textsuperscript{13}

**Hemodynamic Correlates of RVEF**

Right ventricular ejection fraction was reduced in patients with valvular heart disease in relation to the elevation of the RVSP. Patients with RVSPs below 50 mm Hg had a mean RVEF of 51 percent, while patients with RVSPs above 50 mm Hg had a mean RVEF of 45 percent. A reduced RVEF in the setting of increased afterload is consistent with previous experimental and clinical studies of the effect of increased pressure load on ejection fraction.\textsuperscript{27-31} Nevertheless, in this, as in other clinical studies of right and left ventricular pressure overload, the majority of patients with severe pressure overload use compensatory mechanisms to maintain ejection fraction within the range of normal.\textsuperscript{11,28,30,31} The RVEF and peak RVSP were not linearly correlated. In left ventricular pressure overload owing to aortic stenosis, a similar lack of correlation between LVEF and LVSP has also been shown.\textsuperscript{30} The lack of linear correlation between RVEF and systolic pressure is also reflected in the fact that patients with mitral disease had more severe elevations in pulmonary artery and pulmonary capillary wedge pressures than did patients with aortic valve disease, and yet their mean ejection fractions did not differ. These data are consistent with the hypothesis that systolic pressure (afterload) is only one of a number of determinants of ejection fraction, including adequacy of compensatory hypertrophy, preload, heart rate, and contractile state.\textsuperscript{32}

Although one would anticipate an association between a reduction in RVEF and an elevation in RVFP (right atrial pressure), no such relation was found in this study. This might be because the two were measured at different times and under different conditions. Nevertheless, in patients with aortic or mitral valve disease, a similar lack of correlation between LVEF and LVFP has been noted, even when these valves were simultaneously measured.\textsuperscript{38,39} Right atrial pressure might be normal with a low RVEF as a result of vigorous diuresis. Conversely, an elevated right atrial pressure could occur with a normal RVEF with tricuspid regurgitation or with excessive fluid retention owing to severe left-sided valvular disease.\textsuperscript{34} These data suggest that right heart pressure measurements do not predict RVEF in patients with aortic or mitral valve disease or both. Therefore, radionuclide right ventriculography appears to be necessary to supplement measurement of right heart pressures in order to assess reliably right ventricular systolic function in these patients.

**Ejection Fraction as an Indicator of Prognosis**

Although one might anticipate that a reduced RVEF would be a predictor of a worse prognosis, in this study the early postoperative survival was similar when patients with normal and depressed RVEFs were compared. This finding is similar to observations in patients with pressure overload on the left ventricle, indicating that early survival following correction of aortic stenosis similarly is not closely related to whether the preoperative left ventricular ejection fraction was normal or reduced.\textsuperscript{35-38} There were slight differences in the number of patients with prolonged intubation and hospitalizations; however, this difference was not statistically significant, perhaps as a result of the limited number of patients studied. Therefore, although the reduced measured ejection fraction has significance in terms of reflecting pressure overload, the reduction in ejection fraction does not necessarily reflect a worse prognosis. Although these patients were not studied postoperatively, prior studies suggest that the ejection fraction returns toward normal after reduction in pulmonary artery pressures.\textsuperscript{39}

**Central Vein Reflux**

The gated first-pass technique also allows recording of images of the venous channels entering the right heart, which permits visualization of tracer reflux into the right brachiocephalic vein, hepatic veins, or inferior vena cava. Tracer reflux was not found in control patients, but was present in 25 percent of patients with RVSPs less than 50 mm Hg and in 88 percent with RVSPs above 50 mm Hg. The presence of reflux was not related to the level of right atrial pressure.

An explanation for the frequent finding of central venous reflux in valvular patients with pulmonary hypertension is not known. It may indicate the presence of tricuspid regurgitation. All ten patients with clinically evident tricuspid insufficiency had tracer reflux. However, many patients with reflux showed no clinical evidence of tricuspid regurgita-
tion. These patients may also have had tricuspid regurgitation causing the reflux observed, because functional tricuspid regurgitation is a common sequelae of advanced pulmonary hypertension in left-sided valvular disease.5,33,40 Because of the known difficulties in documenting tricuspid regurgitation, this could not be confirmed. Another possible explanation is that the RVSPs produce increased excursion of the tricuspid valve into the right atrium without actual regurgitation, thereby displacing some tracer into the inferior vena cava or brachiocephalic veins. Therefore, although reflux was not found in any control patients, its presence does not necessarily mean that there is tricuspid regurgitation.

Clinical Implications

A multiple gated first-pass radionuclide approach may be used to assess right ventricular function in patients with valvular heart disease. This permits visualization of right ventricular contraction in addition to ejection fraction measurement without overlap of blood-pool activity from any other cardiac chamber. Right ventricular ejection fraction appears to decrease in about one-half of the patients with elevation of RVSP and appears to be unrelated to RVFP. Reduction in RVEF does not appear to predict a worse clinical course early after surgical correction of the valvular disease. Reflux of tracer activity seen on the first-pass study may suggest increased right ventricular afterload or tricuspid regurgitation of both. Radionuclide angiographic assessment of right ventricular function provides information not evident by clinical and hemodynamic evaluation.

ACKNOWLEDGMENT: The authors wish to express their gratitude to Shannon L. Riley for assistance in the preparation of this manuscript.

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