Comparative effects of volume loading, dobutamine, and nitroprusside in patients with predominant right ventricular infarction

LOUIS J. DELL’ITALIA, M.D., MARK R. STARLING, M.D., RALPH BLUMHARDT, M.D., JOHN C. LASHER, M.D., AND ROBERT A. O’ROURKE, M.D.

ABSTRACT To assess the value of volume loading and to determine the relative efficacy of dobutamine compared with nitroprusside therapy in acute right ventricular infarction (RVMI), 13 patients with clinical, hemodynamic, and radionuclide angiographic evidence of RVMI were evaluated. In 10 patients who had an initial pulmonary arterial wedge pressure less than 18 mm Hg, volume loading did not improve cardiac index (1.9 ± 0.5 [SD] to 2.1 ± 0.4 liters/min/m²), despite significant increases in mean right atrial pressure (11 ± 2 to 15 ± 2 mm Hg, p < .001) and pulmonary arterial wedge pressure (10 ± 4 to 15 ± 2 mm Hg, p < .001). Nine patients received dobutamine or nitroprusside in random order, while hemodynamic measurements and radionuclide angiograms were obtained simultaneously. Compared with nitroprusside, dobutamine produced a statistically significant increase in cardiac index (2.0 ± 0.4 to 2.7 ± 0.5 vs 2.1 ± 0.4 to 2.3 ± 0.5 liters/min/m², p < .001), stroke volume index (29 ± 6 to 36 ± 8 vs 29 ± 6 to 30 ± 6 ml/m², p = .02), and right ventricular ejection fraction (30 ± 8% to 42 ± 7% vs 34 ± 8% to 37 ± 4%, p < .01) by two-way analysis of variance. We conclude that volume loading does not improve cardiac index in patients with acute RVMI despite a rise in cardiac filling pressures and that infusion of dobutamine, after appropriate volume loading, produces a significant improvement in cardiac index and right ventricular ejection fraction over those after infusion of nitroprusside.


INFARCTION of the right ventricle commonly occurs with acute inferior transmural myocardial infarction.1, 2 Because of the variable extent of right ventricular damage, patients may present with a spectrum of hemodynamic characteristics.3 When right ventricular myocardial infarction (RVMI) is associated with decreased cardiac index and systolic arterial blood pressure, volume loading has been advocated based on work in animals by Guiha and Cohn4 and Goldstein et al.5, 6 Conversely, in a substantial number of patients with hemodynamically important RVMI, we and others have found that volume loading alone did not improve cardiac index. However, in patients whose conditions are refractory to volume loading alone, other investigators have reported an improvement in cardiac index with the infusion of dobutamine5, 10 or nitroprusside.11, 12 This information concerning the beneficial effects of dobutamine and nitroprusside is derived from case reports involving a total of three patients. Because no study has systematically evaluated these potential therapies in an adequate number of patients with acute RVMI, no rational approach to the treatment of this complex hemodynamic syndrome has evolved. Accordingly, the purpose of this study was to evaluate the potential salutary effects of volume loading and to determine the relative efficacy of dobutamine and nitroprusside therapy, in addition to volume loading, in patients with hemodynamically important RVMI.

Methods

Patients. The study group (n = 13) was made up of consecutive patients who presented with (1) a history of prolonged chest pain consistent with myocardial ischemia, (2) pathologic Q waves of at least 0.04 sec in duration with a Q:R ratio of at least 1:4 in leads II, III, and aVF and associated ST-T wave changes, and (3) the elevation of serum levels of total creatine kinase and its MB isoenzyme fraction.13 Potential study patients with right ventricular infarction were identified within 48 hr of the onset of
TABLE 1
Mean hemodynamic data in the 13 study patients before and after therapy with normal saline (n = 10), dobutamine (n = 12), and nitroprusside (n = 10)

<table>
<thead>
<tr>
<th></th>
<th>RAP (mm Hg)</th>
<th>PAWP (mm Hg)</th>
<th>RA/PAWP ratio</th>
<th>PA (mm Hg)</th>
<th>CI (l/min/m²)</th>
<th>SVI (ml/m²)</th>
<th>RVSWI (g·m⁻²)</th>
<th>LVSWI (g·m⁻²)</th>
<th>HR (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>11 ± 2</td>
<td>10 ± 4</td>
<td>1.3 ± 0.9</td>
<td>18 ± 4</td>
<td>1.9 ± 0.5</td>
<td>27 ± 5</td>
<td>2.5 ± 1.4</td>
<td>30 ± 6</td>
<td>73 ± 11</td>
</tr>
<tr>
<td>Normal saline</td>
<td>15 ± 2⁵⁷</td>
<td>15 ± 2⁵⁷</td>
<td>1.0 ± 0.2</td>
<td>22 ± 4⁵⁷</td>
<td>2.1 ± 0.4</td>
<td>29 ± 5</td>
<td>2.8 ± 1.5</td>
<td>32 ± 8</td>
<td>72 ± 11</td>
</tr>
<tr>
<td>Control</td>
<td>15 ± 2</td>
<td>15 ± 3</td>
<td>1.0 ± 0.2</td>
<td>21 ± 3</td>
<td>2.1 ± 0.4</td>
<td>30 ± 6</td>
<td>2.6 ± 1.6</td>
<td>33 ± 11</td>
<td>71 ± 11</td>
</tr>
<tr>
<td>Dobutamine</td>
<td>13 ± ³</td>
<td>16 ± 4</td>
<td>0.8 ± 0.2²</td>
<td>24 ± ³</td>
<td>2.8 ± 0.6²</td>
<td>36 ± ⁷²</td>
<td>5.4 ± 2.1³</td>
<td>41 ± 11⁷³</td>
<td>79 ± 13⁷³</td>
</tr>
<tr>
<td>Control</td>
<td>14 ± 4</td>
<td>14 ± 5</td>
<td>1.1 ± 0.3</td>
<td>21 ± 4</td>
<td>2.0 ± 0.3</td>
<td>29 ± 6</td>
<td>2.6 ± 1.1</td>
<td>30 ± 4</td>
<td>72 ± 12</td>
</tr>
<tr>
<td>Nitroprusside</td>
<td>12 ± ⁴</td>
<td>12 ± 5</td>
<td>1.1 ± 0.3</td>
<td>18 ± ⁴</td>
<td>2.2 ± 0.5⁴</td>
<td>30 ± 6</td>
<td>2.5 ± 1.6</td>
<td>28 ± 6</td>
<td>75 ± 12⁴</td>
</tr>
</tbody>
</table>

RAP = right atrial pressure; PAWP = pulmonary arterial wedge pressure; PA = mean pulmonary arterial pressure; CI = cardiac index; SVI = stroke volume index; RVSWI = right ventricular stroke work index; LVSWI = left ventricular stroke work index; HR = heart rate; BP = mean arterial pressure; SVR = systemic vascular resistance; TPR = total pulmonary resistance; PVR = pulmonary vascular resistance.

*p < .05; †p < .01; ‡p < .001 for control vs intervention.

symptoms by the following combined criteria: (1) elevated jugular venous pressure (≥ 8 cm H₂O) or Kussmaul's sign; and (2) evidence of both reduced equilibrium radionuclide angiographic right ventricular ejection fraction (<40%) and right ventricular wall motion abnormalities of akinesia or dyskinesia. After written informed consent was obtained on a form approved by our Institutional Review Board, right heart catheterization was performed in all patients who met the physical examination and radionuclide angiographic criteria for RVMI. The final study group of 13 patients was subsequently defined by the presence of hemodynamic criteria for RVMI either before or after volume infusion. Thus, all study patients fulfilled the clinical, hemodynamic, and radionuclide angiographic criteria for RVMI.

The 13 study patients consisted of nine men and four women with ages ranging from 40 to 75 years (mean 55). Two patients had a history of a prior nontransmural myocardial infarction. Also, eight of the 13 study patients had a well-documented history of hypertension. Patients with a history of severe chronic obstructive lung disease, left-to-right shunts, renal failure, pulmonary embolus, peripartum cardiomyopathy, and biventricular congestive heart failure were excluded from this study.

**Hemodynamics.** A No. 7 balloon-tip, flow-directed Edward’s catheter (American Edwards Laboratories, Santa Anna, CA) was inserted into the right heart within 48 hr of the onset of symptoms in each patient. With Statham P23 Db transducers (Gould Inc., Oxnard, CA) leveled at the mid-axillary line, calibrated pressures were recorded from the right atrium, right ventricle, pulmonary artery, and pulmonary arterial wedge positions. Cardiac output (CO) was determined by triplicate by the thermodilution technique with an Edwards 9520A cardiac output computer (American Edwards Laboratories, Santa Ana, CA); heart rate (HR) and systemic arterial pressure (cuff sphygmomanometer) were recorded. From these data, the cardiac index (CI), stroke volume index (SVI), right ventricular stroke work index (RVSWI), left ventricular stroke work index (LVSWI), systemic vascular resistance (SVR), total pulmonary resistance (TPR), and pulmonary vascular resistance (PVR) were calculated as: CI = CO/BSA (liters/min/m²); SVI = CI/HR × 1000 ml/m²; RVSWI = RVSWI ÷ (MPA-RAP) × 0.0136 g/m²; LVSWI = SVI × (MAP-PAWP) ÷ 0.0136 g/m²; SVR = MAP-PAWP/CO × 80 dynes/sec/cm²; TPR = MPA/CO × 80 dynes/sec/cm²; PVR = MPA-PAPW/CO × 80 dynes/sec/cm²; where BSA = body surface area (m²); MPA = mean pulmonary arterial pressure; MAP = mean arterial pressure; RAP = right atrial pressure; PAWP = pulmonary arterial wedge pressure.

**Radionuclide angiography.** Equilibrium radionuclide angiography was performed with a 37 photon multiplier tube single crystal gamma scintillation camera equipped with an all-purpose parallel-hole collimator. Labeling of red blood cells in vivo was accomplished by intravenous administration of stannous pyrophosphate followed in 15 min by 25 mCi of ⁹⁹ᵐTc pertechnetate. Images were acquired in the anterior and left anterior oblique projections, which best separated the right and left ventricles in the plane of the interventricular septum. Electrocardiographically gated radionuclide angiographic images were obtained in 64 × 64 byte mode matrix at 30 msec intervals throughout the cardiac cycle to 250,000 counts per frame. A dedicated computer cart was used for data acquisition and processing. The radionuclide angiographic images were initially reviewed in movie format to assess overall qualitative right ventricular wall motion. The apex, inferior and lateral walls, and outflow tract of the right ventricle were evaluated. Right ventricular ejection fraction was calculated by the technique described by Maddahi et al. The radionuclide criteria for RVMI included both a right ventricular ejection fraction of less than 40% and the presence of regional right ventricular wall motion abnormalities of akinesia or dyskinesia. During each phase of the protocol, radionuclide images were obtained and attenuation-corrected right and left ventricular volumes were calculated by a technique that has been previously validated in our laboratory.¹⁷⁻¹⁹

**Protocol.** The protocol consisted of the simultaneous acquisition of radionuclide angiograms and hemodynamic measurements at baseline, after volume loading with normal saline if indicated, during the peak drug effect of dobutamine and nitroprusside, and during a control period between the infusion of each drug. Nine of the 13 study patients received both a dobutamine and nitroprusside infusion in the following random sequence of administration: (1) control 1, (2) drug A, (3) control 2 (20 to 30 min after end of infusion of drug A), and (4) drug B. Seven of the nine patients had pulmonary arterial wedge pressures of less than 15 mm Hg at baseline, and these patients received volume infusions as indicated below.

Ten of the 13 study patients received normal saline in 200 ml increments over 5 min for a total infusion ranging from 200 to 800 ml. The volume infusion was continued until the pulmonary arterial wedge pressure was greater than 15 mm Hg. Three patients did not undergo volume loading because their pulmo-

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monary arterial wedge pressures were greater than 18 mm Hg at baseline. There were no complications of volume loading.

Dobutamine was infused in 12 of the 13 study patients starting at an infusion rate of 2.5 μg/kg/min and increasing to a maximum of 20 μg/kg/min, or until the mean arterial pressure or heart rate increased 10% or more above the baseline value. The infusion rate ranged from 5 to 20 μg/kg/min (mean 13). Three patients had complications related to the dobutamine infusion, including (1) supraventricular tachyarrhythmia requiring cessation of the drug therapy, (2) atrial fibrillation occurring after the discontinuation of the drug, and (3) chest pain, which occurred after the radionuclide and hemodynamic acquisitions, requiring termination of the drug infusion.

Nitroprusside was infused in 10 of the 13 patients. The infusion rate ranged from 0.4 to 2.1 μg/kg/min (mean = 1.2) and was aimed at achieving a 10% decrease in mean arterial pressure with less than 10% increase in the heart rate. There were no complications associated with nitroprusside infusion. Two patients did not receive a nitroprusside infusion due to the complications that occurred during the prior dobutamine infusion, and one patient, whose mean arterial pressure was elevated at baseline, developed unexplained sinus tachycardia without a 10% decrease in mean arterial pressure.

Statistical analysis. Radionuclide right and left ventricular volumes and ejection fractions were calculated by a technician who was blinded to the hemodynamic results. Continuous data are presented as the mean ± SD. Paired Student’s t test was performed to identify differences in hemodynamic and radionuclide angiographic values obtained before and after volume loading (10 patients), dobutamine infusion (12 patients), and nitroprusside infusion (10 patients). In the nine patients who received both dobutamine and nitroprusside infusions, one-way and two-way analyses of variance were performed to determine whether differences existed between the hemodynamic and radionuclide angiographic values obtained during the two control periods and during the nitroprusside and dobutamine infusions. When a difference was found, Bonferroni-corrected multiple t tests were performed to identify intergroup differences. A value of .05 or less was considered to indicate a significant difference.

Results

Volume loading (n = 10). The mean control cardiac and stroke volume indexes were depressed in the 10 patients who received a normal saline infusion (1.9 ± 0.5 liters/min/m² and 27 ± 5 ml/m², respectively). Volume infusion increased the right atrial pressure (11 ± 2 to 15 ± 2 mm Hg, p < .001) and pulmonary arterial wedge pressure (10 ± 4 to 15 ± 2 mm Hg, p < .001). Despite increases in these fillings pressures, cardiac index and stroke volume index did not change significantly. Right and left ventricular stroke work indexes were also initially reduced (2.5 ± 1.4 and 30 ± 6 g·m/m², respectively), and they did not change significantly with the volume infusion. Also, heart rate, mean arterial pressure, systemic vascular resistance, total pulmonary resistance, and pulmonary vascular resistance did not change significantly with volume infusion.

Radionuclide angiography (table 2). Baseline right ventricular end-diastolic and end-systolic volumes in the 10 patients who received a volume infusion were elevated, and right ventricular ejection fraction was depressed (34 ± 5%). However, left ventricular end-diastolic and end-systolic volumes were within the normal range, and left ventricular ejection fraction was 60 ± 12%. After an infusion of normal saline, right and left ventricular volumes and ejection fractions did not change significantly.

| TABLE 2 |
| Mean radionuclide angiographic volumes and ejection fractions before and after therapy with normal saline (n = 10), dobutamine (n = 12), and nitroprusside (n = 10) |

<table>
<thead>
<tr>
<th></th>
<th>RVEDV (ml)</th>
<th>RVESV (ml)</th>
<th>RVEF (%)</th>
<th>LVEDV (ml)</th>
<th>LVESV (ml)</th>
<th>LVEF (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>161 ± 47</td>
<td>107 ± 29</td>
<td>34 ± 5</td>
<td>113 ± 57</td>
<td>49 ± 35</td>
<td>60 ± 12</td>
</tr>
<tr>
<td>Normal saline</td>
<td>168 ± 57</td>
<td>115 ± 39</td>
<td>32 ± 8</td>
<td>112 ± 53</td>
<td>48 ± 32</td>
<td>60 ± 11</td>
</tr>
<tr>
<td>Control</td>
<td>159 ± 54</td>
<td>110 ± 37</td>
<td>31 ± 7</td>
<td>124 ± 55</td>
<td>53 ± 32</td>
<td>60 ± 12</td>
</tr>
<tr>
<td>Dobutamine</td>
<td>154 ± 58</td>
<td>89 ± 30 ²</td>
<td>42 ± 7 ³</td>
<td>131 ± 59</td>
<td>46 ± 27 ²</td>
<td>67 ± 12 ³</td>
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<tr>
<td>Control</td>
<td>165 ± 95</td>
<td>117 ± 86</td>
<td>32 ± 10</td>
<td>110 ± 38</td>
<td>43 ± 22</td>
<td>61 ± 12</td>
</tr>
<tr>
<td>Nitroprusside</td>
<td>153 ± 92</td>
<td>107 ± 86</td>
<td>34 ± 9</td>
<td>106 ± 33</td>
<td>36 ± 21</td>
<td>68 ± 13 ³</td>
</tr>
</tbody>
</table>

RVEDV = right ventricular end-diastolic volume; RVESV = right ventricular end-systolic volume; RVEF = right ventricular ejection fraction; LVEDV = left ventricular end-diastolic volume; LVESV = left ventricular end-systolic volume; LVEF = left ventricular ejection fraction.

* p < .05; ** p < .01; *** p < .001 for control vs intervention.

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Dobutamine infusion (n = 12)

Hemodynamics (table 1). Because 10 of the 12 patients who received a dobutamine infusion also had received normal saline, the control right atrial and pulmonary arterial wedge pressures were 15 ± 2 and 15 ± 3 mm Hg, respectively. During infusion of dobutamine, right atrial pressure decreased to 13 ± 3 mm Hg (p < .05), while pulmonary arterial wedge pressure did not change significantly. During infusion of dobutamine, there were significant increases, compared with the control values, in cardiac index (2.1 ± 0.4 to 2.8 ± 0.6 liters/min/m², p < .001) and stroke volume index (30 ± 6 to 36 ± 7 ml/m², p < .001). Because of this improvement, there was a decrease in systemic vascular resistance from 1699 ± 508 to 1363 ± 352 dynes-sec/cm² (p < .01), while mean arterial pressure did not change significantly. In addition, right and left ventricular stroke work indexes increased from 2.6 ± 1.6 to 5.4 ± 2.1 (p < .001) and from 33 ± 11 to 41 ± 11 g·m/m² (p < .01), respectively. The pulmonary vascular resistance did not change significantly.

Radionuclide angiography (table 2). During the infusion of dobutamine right ventricular ejection fraction improved from 31 ± 7 to 42 ± 7% (p < .001) as a result of a decrease in right ventricular end-systolic volume (110 ± 37 to 89 ± 30 ml, p < .001) and the lack of a significant change in end-diastolic volume. Also, left ventricular ejection fraction increased from 60 ± 12% to 67 ± 12% (p < .001) owing to a decrease in left ventricular end-systolic volume from 53 ± 32 to 46 ± 27 ml (p < .01) and the lack of a significant change in end-diastolic volume.

Nitroprusside infusion (n = 10)

Hemodynamics (table 1). Eight of the 10 patients received a volume infusion before receiving nitroprusside; consequently, the control right atrial and pulmonary arterial wedge pressures were 14 ± 4 and 14 ± 5 mm Hg, respectively. The right atrial and pulmonary arterial wedge pressures decreased during the infusion of nitroprusside to 12 ± 4 mm Hg (p < .05) and 12 ± 5 mm Hg, respectively. As required by the protocol, the mean arterial pressure decreased from 93 ± 18 to 82 ± 16 mm Hg (p < .01). There was an increase in cardiac index from 2.0 ± 0.3 to 2.2 ± 0.5 liters/min/m² (p < .05), which was due to an increase in heart rate (72 ± 12 to 75 ± 12 beats/min, p < .05). The stroke volume index did not change significantly. The observed decrease in systemic vascular resistance from 1706 ± 556 to 1398 ± 498 dynes-sec/cm² (p < .01) was due primarily to the decrease in mean arterial pressure.

Radionuclide angiography (table 2). During the infusion of nitroprusside, the right and left ventricular volumes all decreased, but these changes were not significant. The right ventricular ejection fraction also did not change significantly; however, the left ventricular ejection fraction increased from 61 ± 12% to 68 ± 13% (p < .05). This was due to a greater decrease in left ventricular end-systolic volume compared with that in end-diastolic volume.

Comparison of dobutamine and nitroprusside therapy. On data from the nine patients who completed the protocol, a one-way analysis of variance was performed to determine whether differences existed in the loading conditions on the right and left ventricles during the two control periods. The mean right atrial, pulmonary arterial, pulmonary arterial wedge, and systemic arterial pressures and pulmonary and systemic vascular resistances did not differ during the control periods. In addition, the mean right and left ventricular end-diastolic volumes were similar during the two control periods. Therefore, the loading conditions in both ventricles were comparable before initiating the random infusion of each drug.

A two-way analysis of variance was performed to determine whether a significant difference existed between values obtained during the infusion of the two drugs (figure 1). The cardiac and stroke volume indexes increased more during the infusion of dobutamine than during the infusion of nitroprusside (2.0 ± 0.4 to 2.7 ± 0.5 vs 2.1 ± 0.4 to 2.3 ± 0.5 liters/min/m², p < .001; and 29 ± 6 to 36 ± 8 vs 29 ± 6 to 30 ± 6 ml/m², p = .02, respectively). The increase in right ventricular ejection fraction during the infusion of dobutamine was greater than that during the infusion of nitroprusside, the right and left ventricular volumes all decreased, but these changes were not significant.

FIGURE 1. Results of two-way analysis of variance comparing the effects of dobutamine (D) and nitroprusside (N) therapy on cardiac index (CI), stroke volume index (SVI), right ventricular ejection fraction (RVEF), right ventricular end-diastolic volume (RVEDV), and right ventricular end-systolic volume (RVESV) in the nine patients receiving both drugs as outlined in the protocol. Significant differences are noted as follows: **p < .001; *p = .02; †p < .01.
nitroprusside (30 ± 8% to 42 ± 7% vs 34 ± 8% to 37 ± 4%, p < .01, respectively). This difference reflected a greater increase in stroke volume during the dobutamine infusion, since end-systolic volume decreased significantly (p < .01) and end-diastolic volume remained unchanged. In contrast, during the infusion of nitroprusside, there was a commensurate decrease in both end-diastolic and end-systolic volumes, producing no change in stroke volume. These changes paralleled the hemodynamic changes described above.

Discussion

Since the original reports by Cohn and Guiha and their colleagues in 1974, volume loading has been the mainstay of therapy for treatment of the low cardiac output state in acute RVMI. Subsequently, we and others have found that volume therapy did not improve cardiac output in a group of patients with hemodynamically important RVMI. Lopez-Sendon et al. rapidly infused dextran into the right atrium of 36 patients with acute RVMI until either the right atrial or pulmonary arterial wedge pressure increased more than 5 mm Hg, or until cardiac output decreased. They found that volume loading increased filling pressures but did not significantly improve cardiac output for the group, and in many instances, it produced a decrease in cardiac output. They concluded that the pulmonary arterial wedge pressure may not reflect the true preload or end-diastolic volume of the left ventricle. Thus, therapy should aim for an optimal cardiac index rather than a specific pulmonary arterial wedge pressure, since copious volume infusions may produce a decrease in cardiac output.

This concept was nicely demonstrated by Goldstein et al. in their closed pericardial dog preparation of acute RVMI. After acute right coronary arterial occlusion, volume loading increased the left ventricular end-diastolic pressure from 7 to 12 mm Hg, and there was a small but significant increase in cardiac output. However, after the pericardium was removed, the left ventricular end-diastolic pressure decreased to 11 mm Hg and the left ventricular volumes and cardiac output increased significantly over the post-volume load values when the pericardium was intact. Thus, despite a significant increase in the left ventricular end-diastolic pressure after volume loading, the true distending pressure or transmural pressure of the left ventricle was diminished owing to an increased intrapericardial pressure. This finding corroborates other studies in animals and man that suggest that acute distension of the right ventricle encroaches upon the left ventricle, with a subsequent decrease in the septal-to-free wall left ventricular diameter, despite a rise in left ventricular end-diastolic pressure.

Volume loading. The basic pathophysiology of acute RVMI as demonstrated in the animal preparation of Goldstein et al. is exemplified in our patient population by the following: an increased right atrial pressure, low cardiac index, increased right ventricular volumes with a markedly depressed right ventricular ejection fraction, and normal left ventricular volumes and ejection fraction. After a volume infusion, the following occurred: (1) both the right atrial and pulmonary arterial wedge pressures increased significantly, but cardiac index did not improve, (2) left ventricular end-diastolic volume and left ventricular ejection fraction did not change, and (3) right ventricular end-diastolic volume increased and right ventricular ejection fraction decreased slightly but not significantly. Thus, by further increasing right ventricular cavity size, volume loading may limit left ventricular filling through a mechanism of ventricular interaction due partly to the effects of the intact pericardium. Furthermore, increases in intracavitary pressure and radius may increase wall stress of the thin-walled right ventricle. This, in turn, may decrease right ventricular ejection fraction and right ventricular stroke volume, thereby further depressing forward cardiac output and systemic arterial pressure as demonstrated in a subset of patients studied by Lopez-Sendon et al.

Dobutamine infusion. Dobutamine significantly increased cardiac and stroke volume indexes in our patients with acute RVMI by a direct augmentation in right ventricular systolic performance, as evidenced by a significant increase in right ventricular ejection fraction. This was accomplished through improved wall motion of hypokinetic wall segments, while akinetic and dyskinetic wall segments remained largely unchanged. In most cases, right ventricular lateral wall and outflow tract demonstrated normal to hypokinetic wall motion during the control study, and these segments became hyperkinetic during the infusion of dobutamine (figure 2). In addition, left ventricular systolic performance improved significantly over generally normal systolic function owing to improvement in normal and hypokinetic wall segments. The increases in hemodynamically determined cardiac and stroke volume indexes were paralleled by increases in radionuclide angiographic stroke volumes of the right and left ventricles.

In the hypotensive patient, there are theoretical contraindications to the use of dobutamine because of its weak systemic vasoconstrictor effect. However, six patients had systolic blood pressures ranging between

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TABLE 3
Mean hemodynamic and radionuclide angiographic data before and after dobutamine in six patients with an initial systolic pressure less than 110 mm Hg

<table>
<thead>
<tr>
<th></th>
<th>RAP (mm Hg)</th>
<th>PAWP (mm Hg)</th>
<th>PA (mm Hg)</th>
<th>CI (l/min/m²)</th>
<th>SVI (ml/m²)</th>
<th>HR (bpm)</th>
<th>MAP (mm Hg)</th>
<th>SVR (dynes/sec-cm²)</th>
<th>RVEDV (ml)</th>
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<tbody>
<tr>
<td>Control</td>
<td>15 ± 3</td>
<td>15 ± 3</td>
<td>22 ± 3</td>
<td>2.1 ± 0.4</td>
<td>31 ± 6</td>
<td>68 ± 11</td>
<td>83 ± 6</td>
<td>1372 ± 431</td>
<td>185 ± 61</td>
</tr>
<tr>
<td>Dobutamine</td>
<td>13 ± 3</td>
<td>17 ± 4</td>
<td>25 ± 4</td>
<td>2.8 ± 0.5c</td>
<td>39 ± 7b</td>
<td>71 ± 12</td>
<td>95 ± 13a</td>
<td>1241 ± 376</td>
<td>183 ± 63</td>
</tr>
</tbody>
</table>

Abbreviations are as in tables 1 and 2.

*p < .05; b p < .01; c p < .005.

90 and 110 mm Hg, and three of these patients had well-documented histories of hypertension. Mean cardiac index, stroke volume index, and systemic arterial pressure increased significantly, and no patient experienced hypotension during the infusion of dobutamine (table 3). Since vascular decompensation resulted from depressed myocardial contractility and not from loss of vascular tone, dobutamine was particularly beneficial in the present study population. However, when a patient presents in profound shock, when loss

FIGURE 2. End-diastolic (left) and end-systolic (right) equilibrium radionuclide angiographic images in the left anterior oblique projection during control, volume loading, and administration of dobutamine and nitroprusside in a representative patient with acute RVMI are shown. A, The right ventricle is markedly enlarged with akinesis of the apex and inferior walls and hypokinesis of the lateral wall. Right ventricular ejection fraction = 31%. The left ventricle is small and the left ventricular ejection fraction = 58%. B, There is no change in right ventricular size and wall motion after a volume load. Right ventricular ejection fraction = 34%; left ventricular ejection fraction = 55%. C, During infusion of dobutamine right ventricular lateral and inferior wall motion markedly improve, producing a smaller end-systolic volume. Right ventricular ejection fraction = 43%. The overlying right atrium (yellow) becomes more prominent owing to enhancement of lateral wall motion. Left ventricular contractility increases, and left ventricular ejection fraction = 69%. D, A second control study was obtained before infusion of nitroprusside and findings were similar to those in B. Nitroprusside did not improve lateral or inferior wall motion. Right ventricular ejection fraction = 33%. Left ventricular contractility is augmented, with a left ventricular ejection fraction = 67%.
of vascular tone and marked hypotension may play a major role in the decompensated state, a positive inotropic agent with some α-adrenergic vasoconstrictive properties may be preferable.

**Nitroprusside infusion.** Despite a significant decrease in mean pulmonary arterial pressure and total pulmonary resistance during the infusion of nitroprusside, there was no improvement in right ventricular systolic performance or stroke volume index in our study population. In contrast, afterload reduction improves right ventricular systolic performance and cardiac index in patients with pulmonary hypertension secondary to chronic obstructive lung disease or chronic left heart failure.23-25 Because patients with significant right ventricular infarction have primary right ventricular pump failure, they usually present with normal to only mildly elevated pulmonary arterial systolic pressures, low pulmonary arterial pulse pressure, and mildly elevated total pulmonary resistance owing to a low cardiac output. Thus, right ventricular afterload does not present a significant obstacle to right ventricular ejection, either by passive elevation of left heart filling pressures or by increased pulmonary vascular resistance, as long as significant left ventricular dysfunction is not present.

Although both right ventricular end-diastolic volume and right atrial pressure demonstrated a tendency to decrease during the infusion of nitroprusside, these changes did not reach statistical significance. Therefore, the lack of improvement in right ventricular ejection fraction and stroke volume index cannot be totally attributed to an excessive decrease in preload during the infusion of nitroprusside, although this is the most likely explanation. In summary, therapy with nitroprusside in addition to volume loading did not improve the overall hemodynamic status of our patients with predominant RVMI.

**Limitations.** The results of this study suggest that volume loading does not improve cardiac index in patients with acute ischemic right ventricular dysfunction. However, one may argue that insufficient volume was given to produce a beneficial effect of the Frank-Starling mechanism, since right and left ventricular end-diastolic volume calculations did not increase significantly after this therapeutic intervention. Nonetheless, after a volume load, each patient had at least a 5 mm Hg increase in the pulmonary arterial wedge pressure, or a final pressure of greater than 15 mm Hg (range 15 to 20 mm Hg); the final right atrial pressure ranged between 14 and 19 mm Hg in each patient. According to the Frank-Starling mechanism, this initial rise in right- and left-sided filling pressures should have increased cardiac index, since the early portion of the cardiac function curve demonstrates the steepest slope in the relationship of stroke volume to filling pressure. After the achievement of an initial rise in filling pressures and an adequate sinal pulmonary arterial wedge pressure, a failure to increase cardiac index suggests that function in these patients was on the flat portion of the ventricular function curve and therefore, further volume loading could not improve forward cardiac output.

Although dobutamine significantly improved cardiac and stroke volume indexes, there was a significant increase in heart rate and mean arterial pressure, and the pulmonary arterial wedge pressure rose slightly. These effects in our patients are in direct contrast to the findings in patients with acute myocardial infarction and significant left ventricular dysfunction, in whom the infusion of dobutamine does not change heart rate or mean arterial pressure, while it does cause a decrease in the pulmonary arterial wedge pressure.26, 27 Recently, Pacold et al.28 demonstrated a significant increase in heart rate and blood pressure during low dose dobutamine infusion in 13 patients with chronic coronary artery disease and normal to minimally depressed left ventricular function. In these patients, myocardial ischemia was documented by a significant decrease in myocardial lactate extraction and a significant increase in mean ST segment depression. In our patient population with nearly normal left ventricular function, it is unlikely that the increased myocardial oxygen demands of dobutamine were offset by a decrease in left ventricular size and wall tension, as usually occurs in patients with severe congestive heart failure. Therefore, use of dobutamine in patients with predominant right ventricular dysfunction may induce ischemia, as it did in one of our patients. Nonetheless, systemic arterial hypotension and decreased cardiac index are the main indications for treatment of patients with acute RVMI; the subsequent improvement in pressure and cardiac index should augment myocardial blood flow and offset any increase in myocardial oxygen demand by an increase in systemic arterial and coronary perfusion pressures during the infusion of dobutamine.
Although each patient in the protocol had unequivocal clinical, hemodynamic, and radionuclide angiographic evidence of RVMI, no patient was severely hypotensive at the start of the protocol. However, eight of the 13 study patients had a well-documented history of hypotension, and the mean arterial pressure for the group reflected relative hypotension when compared with preinfarction level. One patient (table 3) presented with a systolic blood pressure of 70 mm Hg, and concomitant volume loading (300 ml normal saline) and dobutamine subsequently raised his systolic arterial pressure to 100 mm Hg. After a stable hemodynamic condition was attained, dobutamine was discontinued and the complete protocol was performed. The protocol excluded patients with chronic left heart failure. In addition, none of our patients with right ventricular infarction had concomitant extensive infarction of the left ventricle. Thus, there were no patients in the study group who had significant right and left ventricular dysfunction. These patients are the most difficult to treat, and we and others have found that this subgroup of patients has the highest acute mortality, irrespective of the mode of therapy employed.\textsuperscript{7, 29-30} In addition, Legrand et al.\textsuperscript{31} reported that the 6 month mortality in 46 patients with RVMI was related to severe left ventricular disease in five of the six cases.

**Conclusions.** Right ventricular infarction is a unique clinical syndrome that differs from infarction that is predominantly of the left ventricle with respect to its acute presentation, therapy, and, most importantly its long-term prognosis. Our data\textsuperscript{7} and the data from other investigators\textsuperscript{32} demonstrate improvement in right ventricular systolic performance over the 6 week to 3 month recovery period. Thus, it appears that if these patients can be supported through the first 2 to 5 days after infarction, the chances of full recovery are excellent if there is predominant right ventricular dysfunction and no extensive impairment of performance of the left ventricle. This underscores the importance of early detection and prompt administration of appropriate therapy to improve acute mortality. In general, an initial volume infusion should be used to achieve an increase of greater than 5 mm Hg, not to exceed a final value of 20 mm Hg, in the pulmonary arterial wedge or right atrial pressure. This initial volume infusion should be carefully administered, and if cardiac output does not improve, then dobutamine should be administered to augment right ventricular systolic performance and improve forward cardiac output.

We appreciate the technical assistance of Ms. Betty Heyl, Suzanne Patrick-Fischer, and Sandra Carr, R.N., and the preparation of this manuscript by Ms. Patricia Krueger.

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Comparative effects of volume loading, dobutamine, and nitroprusside in patients with predominant right ventricular infarction.
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_Circulation_. 1985;72:1327-1335
doi: 10.1161/01.CIR.72.6.1327

_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1985 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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