Right Ventricular Volume Characteristics in Ventricular Septal Defect

THOMAS P. GRAHAM, JR., M.D., GERALD F. ATWOOD, M.D., ROBERT J. BOUCEK, JR., M.D., DYKES CORDELL, M.D., AND ROBERT C. BOERTH, M.D.

SUMMARY Right and left ventricular volume characteristics were determined from biplane cineangiography in 37 patients with isolated ventricular septal defects. Patients were divided into three categories as determined by the degree of left-to-right shunt: small shunt—less than 35% of pulmonary blood flow (N = 9); moderate shunt—35–49% (N = 8), and large shunt—greater than 50% (N = 20). Right ventricular (RV) end-diastolic volume was increased above normal in 15 of 20 studies performed in patients with large left-to-right shunts and averaged 159 ± 10% of normal (P < 0.001). In contrast, only one of the patients in the small shunt group and only half of the patients in the moderate shunt group showed increases in RV end-diastolic volume. The increase in RV volume was proportional to the corresponding increase in left ventricular end-diastolic volume, with the right ventricle ranging from 48 to 116% of LV end-diastolic volume (average 83%). Right ventricular ejection fraction was normal in all patient groups. Right ventricular output was increased commensurate with the increases in the RV end-diastolic volume. These data indicate that substantial augmentation in RV end-diastolic volume does occur in patients with isolated ventricular septal defects and large left-to-right shunts. These data can be explained by the significant diastolic and "isovolumic" shunting from left ventricle to right ventricle which occurs in these patients.

IN AN ISOLATED VENTRICULAR SEPTAL DEFECT (VSD), the major hemodynamic overload has been considered to be on the left side of the heart with consequent increases in left atrial and left ventricular size. These increases in left heart volume variables have been documented and agree well with the degree of left-to-right shunting in patients with VSD. In contrast, however, the right ventricular response to an isolated VSD in terms of ventricular dilatation as a function of degree of left-to-right shunt has not been documented. The purpose of this investigation, therefore, was to determine right ventricular end-diastolic volume, ejection fraction, and systolic output in patients with isolated VSD and to relate these variables to similar left ventricular volume characteristics as well as to other hemodynamic variables reflecting the size of the left-to-right shunt.

From the Division of Pediatric Cardiology, Vanderbilt University Medical Center, Nashville, Tennessee.

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Address for reprints: Thomas P. Graham, Jr., M.D., Professor of Pediatrics, Director of Pediatric Cardiology, Vanderbilt University Medical Center, Nashville, Tennessee 37232.

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Methods Infants and children undergoing cardiac catheterization at Vanderbilt University and having the diagnosis of an isolated ventricular septal defect constitute the study population. Patients with a significant atrial shunt (mixed venous blood to right atrial O₂ saturation stepup of >7%), semilunar valvular incompetence, or atriopulmonary valvular incompetence were excluded from this study. All data were obtained during diagnostic cardiac catheterization. Patients less than six weeks of age received no premedication, but occasionally were given small doses of morphine (0.05 mg/kg). Patients from six weeks to two years of age were sedated with meperidine, 1 mg/kg, and hydroxyzine, 1 mg/kg i.m., given 30 min before the beginning of the catheterization procedure. Occasionally, additional doses of meperidine of 0.1 to 0.5 mg/kg were required for sedation during the procedure. Patients above two years of age were sedated with Innovar, 0.025 ml/kg, up to a maximum of 1 cc i.m. given 30 min prior to the procedure. Rarely, additional doses of Innovar of ¼ to ½ of the original dose were required for sedation. Right and left heart pressures were obtained with NIH catheters with zero
referred to midchest. Right heart pressures were obtained prior to cineangiocardiography. Shunt determinations were made using reflectance oximetry, and percent of left-to-right shunts and Qp/Qs ratios were calculated using the Fick principle. Patients with significant shunts usually also had indicator dilution determinations performed with injection into the right atrium and sampling from a peripheral artery. Right and left heart volume determinations were performed using techniques previously described. These values were related to previously obtained normal values and expressed as a percent of predicted normal.

Patients were divided into three hemodynamic groups in accordance with the degree of left-to-right shunt as determined from oxygen data (table 1). Group 1 includes nine patients who were designated the small group and whose shunts were less than 35% of pulmonary flow. Shunts ranged from no detectable shunt by oximetry (2 patients) to a 31% left-to-right shunt. The diagnosis of ventricular septal defect was confirmed by left ventricular cineangiocardiography in all patients. Group 2 consisted of eight patients who had a moderate shunt as defined by a left-to-right shunt between 35 and 49% of estimated pulmonary flow. There were two patients in this group with markedly elevated right ventricular pressure, secondary to a moderate elevation of pulmonary vascular resistance. These patients had shunts of 45 and 48%, respectively, and had Rp/Rs ratios less than 0.45. Group 3 consisted of 20 studies in 18 patients whose left-to-right shunts ranged from 50 to 85%, with an average of 67%. Table 1 shows hemodynamic and volume data for the three patient groups, along with P values derived from group comparisons. In terms of age and hemodynamic data, group 2 patients differed from group 1 only in having a slightly higher RV peak systolic pressure and a larger shunt. Group 3 differed from the other two groups in having younger patients, larger shunts, slightly higher RV peak systolic pressure, and higher end-diastolic pressure. Group 3 differed from group 2, but not from group 1, in having a slightly higher HR.

**Results**

Right ventricular end-diastolic volume was increased above normal in 15 of 20 studies performed in patients whose left-to-right shunt was equal to or greater than 52% of pulmonary blood flow (fig. 1). Two patients in this group had two studies performed and showed comparable increases in right ventricular end-diastolic volume at the two studies. All but five of the studies clearly show elevated values for end-diastolic volume which are well outside the normal range.

In figure 2 RV end-diastolic volume and LV end-diastolic volume are plotted as a percentage of predicted normal for patients in the large shunt group. Left ventricular end-diastolic volume was increased in all patients, averaging 210% of normal, and right ventricular end-diastolic volume averaged 159% of normal.

Figure 3 shows RV end-diastolic volume as a function of LV volume in the large shunt group. In all but two instances right ventricular volume is smaller than the corresponding left ventricular end-diastolic volume. A regression analysis was performed relating these two variables and a strong

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**Table 1. Hemodynamic and Volume Data for the Three Ventricular Septal Defect Patient Groups**

<table>
<thead>
<tr>
<th>Age (yr)</th>
<th>Group 1 N = 9</th>
<th>Group 2 N = 8</th>
<th>P (2 vs 1)</th>
<th>P (3 vs 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4 ± 0.6</td>
<td>2.9 ± 1.3</td>
<td>NS</td>
<td>0.47 ± 0.12</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>2.0 ± 0.4</td>
<td>2.3 ± 1.0</td>
<td>NS</td>
<td>0.25 ± 0.10</td>
<td>&lt;0.05</td>
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<table>
<thead>
<tr>
<th>HR</th>
<th>Group 1 N = 9</th>
<th>Group 2 N = 8</th>
<th>P (2 vs 1)</th>
<th>P (3 vs 2)</th>
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</thead>
<tbody>
<tr>
<td>122</td>
<td>126</td>
<td>NS</td>
<td>140</td>
<td>&lt;0.04</td>
</tr>
<tr>
<td>150</td>
<td>115</td>
<td>NS</td>
<td>130</td>
<td>&lt;0.02</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>RVP (mm Hg)</th>
<th>Group 1 N = 9</th>
<th>Group 2 N = 8</th>
<th>P (2 vs 1)</th>
<th>P (3 vs 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 ± 5</td>
<td>51</td>
<td>&lt;0.01</td>
<td>66</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>40</td>
<td>60</td>
<td>NS</td>
<td>55</td>
<td>&lt;0.001</td>
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</table>

<table>
<thead>
<tr>
<th>PAP (mm Hg)</th>
<th>Group 1 N = 9</th>
<th>Group 2 N = 8</th>
<th>P (2 vs 1)</th>
<th>P (3 vs 2)</th>
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</thead>
<tbody>
<tr>
<td>27 ± 4</td>
<td>48</td>
<td>&lt;0.01</td>
<td>61</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>35</td>
<td>50</td>
<td>NS</td>
<td>55</td>
<td>&lt;0.001</td>
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</table>

<table>
<thead>
<tr>
<th>PADP (mm Hg)</th>
<th>Group 1 N = 9</th>
<th>Group 2 N = 8</th>
<th>P (2 vs 1)</th>
<th>P (3 vs 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 ± 1</td>
<td>19</td>
<td>&lt;0.05</td>
<td>22</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>11</td>
<td>16</td>
<td>NS</td>
<td>15</td>
<td>&lt;0.001</td>
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</table>

<table>
<thead>
<tr>
<th>RVEDV (%)</th>
<th>Group 1 N = 9</th>
<th>Group 2 N = 8</th>
<th>P (2 vs 1)</th>
<th>P (3 vs 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>101 ± 5</td>
<td>127</td>
<td>&lt;0.01</td>
<td>150</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>92</td>
<td>115</td>
<td>NS</td>
<td>120</td>
<td>&lt;0.001</td>
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<table>
<thead>
<tr>
<th>RVES (%)</th>
<th>Group 1 N = 9</th>
<th>Group 2 N = 8</th>
<th>P (2 vs 1)</th>
<th>P (3 vs 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>107</td>
<td>124</td>
<td>&lt;0.05</td>
<td>159</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>76</td>
<td>98</td>
<td>NS</td>
<td>88</td>
<td>&lt;0.02</td>
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<table>
<thead>
<tr>
<th>LVES (%)</th>
<th>Group 1 N = 9</th>
<th>Group 2 N = 8</th>
<th>P (2 vs 1)</th>
<th>P (3 vs 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>99</td>
<td>149</td>
<td>&lt;0.01</td>
<td>210</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>107</td>
<td>143</td>
<td>NS</td>
<td>135</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LVES (%)</th>
<th>Group 1 N = 9</th>
<th>Group 2 N = 8</th>
<th>P (2 vs 1)</th>
<th>P (3 vs 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.66 ± 0.03</td>
<td>0.66 ± 0.03</td>
<td>NS</td>
<td>0.68 ± 0.02</td>
<td>NS</td>
</tr>
<tr>
<td>0.53-0.78</td>
<td>0.53-0.78</td>
<td>NS</td>
<td>0.50-0.84</td>
<td>NS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LVES (%)</th>
<th>Group 1 N = 9</th>
<th>Group 2 N = 8</th>
<th>P (2 vs 1)</th>
<th>P (3 vs 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>129</td>
<td>138</td>
<td>NS</td>
<td>219</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>101</td>
<td>118</td>
<td>NS</td>
<td>100</td>
<td>&lt;0.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LA Max (%)</th>
<th>Group 1 N = 9</th>
<th>Group 2 N = 8</th>
<th>P (2 vs 1)</th>
<th>P (3 vs 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>136</td>
<td>176</td>
<td>&lt;0.005</td>
<td>243</td>
<td>&lt;0.04</td>
</tr>
<tr>
<td>175-183</td>
<td>157-231</td>
<td>&lt;0.001</td>
<td>172-444</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

All values are means ± standard errors of the mean. The ranges are given below in parentheses. Group 1 = small shunt (<35%); group 2 = moderate shunt (35-49%); group 3 = large shunt (>50%). Abbreviations: RV = peak right ventricular systolic pressure; RVEDV = RV end-diastolic pressure; PAP = pulmonary artery peak pressure; PADP = PA diastolic F; RVES = RV end-diastolic volume as % of predicted normal; RVEF = RV ejection fraction; RVES = RV systolic output = RV stroke output × HR; LMAX = left atrial maximal volume.
relationship was found between these two variables based on either a linear or a nonlinear regression analysis. The highest correlation coefficient ($r = 0.935$) was obtained with an exponential function.

In figure 4 end-diastolic volume is shown for the small, moderate, and large shunt groups. Right ventricular end-diastolic volume averaged 101% of normal in group 1 and was increased above normal in only one patient. In the moderate shunt group, RV end-diastolic volume was increased in half the patients and averaged 127% of normal. In the large shunt group, RV end-diastolic volume was increased in the majority of patients and averaged 159% of normal. Thus, right ventricular volume is increased in the majority of patients with large left-to-right shunts associated with an isolated ventricular septal defect. The degree of enlargement is proportional to the degree of left-to-right shunt as reflected in the enlargement of the left ventricle. All but three patients had infracristal ventricular defects and the three patients with supracristal defects had volumes which appeared to be as large in relation to their shunt size as did patients with infracristal defects. There were no patients with muscular ventricular defects in this patient group.

In these patients, the possibility was considered that significant shunting at the atrial level due to a patent foramen ovale could have contributed to the right ventricular enlargement. Therefore, all 19 patients who had an enlarged right ventricle were re-analyzed to assess this possibility. Four of the 19 patients had oxygen saturation step-ups from mixed venous blood to the right atrium of greater than 3 percentage points. Three of these patients had further evidence of a small atrial shunt on the left atrial phase of a right ventricular or pulmonary artery cineangiogram. One additional patient without a significant atrial oxygen step-up had evidence of a possible small atrial shunt on the right ventricular phase of cineangiography. Mean pressure gradients from LA to RA ranged from 2–8 mm Hg (mean = 4 mm Hg) in these five patients. In addition, these five patients had left atrial volumes which ranged from 172 to 329% of normal suggesting a marked resistance to left-to-right atrial shunting. Thus although the atrial shunts in these five patients were considered to be minor, right ventricular end-diastolic volumes averaged 157% of normal. In the 13

![Figure 1. Right ventricular end-diastolic volume as a function of body surface area for patients with large left-to-right shunts (>50% of pulmonary blood flow). Normal values are indicated by the shaded area. Con. Lim. = confidence limits.](http://circ.ahajournals.org/)

![Figure 2. RV end-diastolic volume and LV end-diastolic volume plotted as a percentage of predicted normal for patients in the large shunt group.](http://circ.ahajournals.org/)

![Figure 3. RV end-diastolic volume as a function of LV volume in the large shunt group. A line of identity is shown. Regression analysis revealed that these two variables were related best with an exponential function: $RV = 1.38(LV)^{0.83}$, ($r = 0.935$).](http://circ.ahajournals.org/)
remaining patients with enlarged right ventricles but no
evidence for atrial shunt either by oximetry or by oxygen
data, right ventricular end-diastolic volume averaged 168% 
of normal. Thus, atrial shunting was not the cause of
enlarged right ventricles for patients in this study.

Right ventricular ejection fraction was also analyzed and
found to be normal in all patient groups. Two patients had
ejection fractions at the lower limits of normal.

Right ventricular systolic output was also analyzed and in
figure 5 right ventricular systolic output is shown as a func-
tion of body surface area for group 3 patients. The
alterations in right ventricular systolic output parallel the
changes in right ventricular end-diastolic volume. Right ven-
tricular output was increased in the majority of patients with
evidence of a large shunt by oximetry and by LV enlarge-
ment.

There was no significant relationship of the right ven-
tricular end-diastolic volume output with either right ven-
tricular peak pressure or right ventricular end-diastolic
pressure when these variables were related to RVEDV by
linear and nonlinear regression analysis.

**Discussion**

The data reported herein indicate that the right ventricle
undergoes considerable dilatation in response to a large,
isolated ventricular septal defect. This degree of dilatation is
related to the size of the left-to-right shunt. Theoretically,
the increase in RV volume in association with a ventricular
defect might be related to the location of the defect. There
were no patients in this series with a muscular ventricular
defect and all but three patients had an infracristal defect.
Three patients with a supracristal defect had enlargement of
their right ventricle in proportion to the size of the shunt,
and thus, the location of the defect had no apparent relation
to the degree of right ventricular enlargement.

We have found a similar relationship between pulmonary
blood flow and right ventricular volume in tetralogy of Fal-
lot patients before and after shunt procedures. Patients who
undergo a successful shunt procedure with an increase in
pulmonary blood flow and enlargement of the left ventricle
do show an increase in size of the right ventricle following
the shunt procedure.4

Fisher et al.4 reported right ventricular volume data on 31
preoperative ventricular septal defect patients. Sixteen of
these patients had a pulmonary-to-systemic flow ratio
greater than 1.5 to 1 and 15 were felt to have a small shunt
with a pulmonary-to-systemic flow ratio less than 1.5 to 1.
These authors state that they were unable to find an increase
in right ventricular end-diastolic volume for this patient
group. The differences between their findings and the find-
ings of the present study possibly may be due only to the fact
that they did not characterize their patient group with
reference to quantitation of the left-to-right shunt except
into those with a Qp/Qs ratio greater than 1.5 to 1 or less
than 1.5 to 1.4 Thus, it is possible that the majority of
patients in their study had only small or moderate shunts
(<2 to 1 Qp/Qs ratio) and RV enlargement was not detect-
able.

The group on which the normal data was based in the
Fisher study4 had a smaller proportion of very young
patients than the group we studied. Their normal group had
70 patients but only seven of the 70 were less than one year
old and the youngest was six months of age. They found only
a linear relationship of RVEDV with body surface area,5
whereas when a greater number of infants are studied the
best relationship between RVEDV and BSA is power func-
tion6—a factor of crucial importance when defining nor-
amal and abnormal volumes in infancy. In this study, the
large shunt group consisted of 20 patients whose ages ranged
from five weeks to 1.7 years with only four patients above one year of age. The need for comparison with normal data obtained in infants of similar age and size is obvious.

In attempting to explain the dilatation of the right ventricle in patients with a ventricular septal defect, the studies of Levin and co-workers are quite interesting. These authors showed significant diastolic shunting from left ventricle to right ventricle in patients with ventricular septal defect, as well as significant augmentation of this shunt with the onset of left ventricular contraction, but before the aortic valve or pulmonary valve opened. These findings can be appreciated in our experience by high speed cineangiography in all patients with a large ventricular septal defect. Thus, the significant degree of intracardiac shunting during diastolic and “isovolumic” contraction undoubtedly is the major factor in producing right ventricular enlargement with a ventricular defect.

Other hemodynamic variables that might relate to the degree of right ventricular dilatation include right ventricular systolic pressure and diastolic pressures. However, there was no significant relationship between RV end-diastolic volume and RV peak systolic pressure or end-diastolic pressure for the entire group because of two factors. First, in the moderate shunt group, there were several patients who had very high right ventricular pressure because of a moderate elevation of pulmonary vascular resistance with only a moderate increase in pulmonary blood flow. Secondly, there were several patients in the large shunt group whose right ventricular pressures were normal or near normal, but who had marked increases in pulmonary blood flow.

The findings of this study indicate that the right ventricle does undergo marked changes in right ventricular volume in response to a large ventricular septal defect. Thus, overall right ventricular function should be considered in long-term evaluation of these patients, before and after surgical procedures.

**Acknowledgment**

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**References**

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