CASE REPORT

Ventricular Function of Single Ventricle After Ventricular Septation

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SUMMARY In this report we describe the follow-up of two patients who underwent total correction (ventricular septation) of a Van Praagh type C single ventricle. At the time of this report the patients are 93 and 37 months after operation, have led a normal life and have nearly normal hemodynamics.

Ventricular cavity volumes were estimated from biplane cineangiograms. In the first patient, left and right ventricular end-diastolic volume indexes (LVEDVI and RVEDVI) were 133 and 98 ml/m², respectively. Left plus right ventricular end-diastolic volume (LVEDV + RVEDV) was approximately 136% of the sum of the normal values of the left and right ventricular volumes. The right-to-left ventricular end-diastolic volume ratio (RVEDV/LVEDV) was 0.74 and the right-to-left ventricular end-systolic volume ratio (RVESV/LVESV) was 0.56. Ejection fractions of the left and right ventricles (LVEF and RVEF) were 0.50 and 0.61, respectively. In the second patient, LVEDVI and RVEDVI were 139 and 93 ml/m², respectively. LVEDV + RVEDV was approximately 166% of the sum of the normal values of the left and right ventricular volumes. RVEDV/LVEDV and RVESV/LVESV were 0.67 and 0.50, respectively. LVEF and RVEF were 0.31 and 0.49, respectively. Cineangiograms showed that the prosthetic ventricular septums shifted toward the right ventricle 7-9 mm in the systolic phase. This movement of the prosthetic septum made LVEF lower than RVEF.

The shift of the prosthetic septum was dependent upon the right ventricular pressure being lower than the left. Cardiac output in response to exercise was excellent in the first patient and poor in the second.

SUCCESSFUL total correction of a single ventricle has been reported many times since the first study by Hallman et al.¹ in 1967. Total correction consists of dividing the single ventricle into two ventricles (ventricular septation). Our experience and that of others have suggested that the result of septation is better when the single ventricle is separated into a smaller right ventricle and a larger left ventricle.²-⁴ However, no reports have described ventricular volume characteristics after septation.

Two patients⁵,⁶ underwent successful total correction of single ventricle at the Osaka University Hospital. Ventricular contractility was assessed after septation by means of biplane cineangiocardiography. In this paper we describe 1) the left and right ventricular volume characteristics, 2) the influence of a prosthetic ventricular septum on ventricular function and 3) the long-term hemodynamic responses to exercise in patients after septation.

Case Report

Case 1

The first patient is an 8-year-old girl who was admitted to the Osaka University Hospital with severe cyanosis, squatting and easy fatigability on exertion. Cardiac catheterization and angiograms were suggestive of tetralogy of Fallot. Total correction was undertaken in March 1970, when the diagnosis of a single ventricle was made. This malformation was classified as a type C according to Van Praagh's classification⁷ and type II according to Kozuka-Kawashima's classification.⁸ The surgery consisted of a pulmonary infundibulectomy and creation of an interventricular septum with a Teflon patch. The prosthetic septum was placed so that the right ventricular volume was smaller than the left. The postoperative course was uneventful except for a temporary complete atrioventricular block. Seven years and 9 months after surgery, she is doing well and leading an active life.

Postoperative Study

Postoperative studies were performed twice, first in July 1973 and then in December 1977. Echocardiograms at the first study revealed the prosthetic septum shifting toward the right ventricle about 15 mm during systole. The pressures in cardiac chambers and great vessels and the cardiac output were within normal range. The data from the second study are as follows: Chest x-ray revealed a cardiothoracic ratio of 0.50, which was unchanged from the preoperative value (fig. 1). The ECG showed an incomplete left bundle branch block. Cardiac catheterization data are listed in table 1.

Cardiac output and ventricular pressure were within normal ranges, as in the first study. In response to

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bicycle ergometer exercise in the supine position with loading of 50 W over 5 minutes, cardiac output was excellent. The cardiac index increased from 3.58 L/min/m² at rest to 6.70 L/min/m² during exercise; stroke volume also increased. Left ventricular end-diastolic pressure (LVEDP) increased from 8 mm Hg at rest to 12 mm Hg during exercise. Right ventricular end-diastolic pressure (RVEDP) also increased from 5 mm Hg at rest to 8 mm Hg during exercise. The right ventricular-to-pulmonary artery pressure gradient was 8 mm Hg during exercise. Right-to-left ventricular systolic pressure ratios were 0.29 at rest and 0.41 during exercise.

Angiographic data are summarized in table 2. Left and right ventricular volumes were obtained by biplane cineangiography. The left ventricular volume was calculated from the right anterior oblique single-plane cinefilms with the regression equation: \( Vt = 0.89 \times Vc + 9.0 \) (ml). Right ventricular volume was calculated from biplane cineangiograms with the regression equation: \( Vt = 0.76 \times Vc - 0.2 \) (ml), where \( Vt \) and \( Vc \) are the true and calculated ventricular volumes, respectively. This equation was proved to be applicable even when the right ventricular cavity is rotated clockwise or counterclockwise.

Left ventricular end-diastolic volume index (LVEDVI) was 133 ml/m², left ventricular end-systolic volume index (LVESVI) was 67 ml/m², and left ventricular ejection fraction (LVEF) was 0.50. In the right ventricle, right ventricular end-diastolic volume index (RVEDVI), right ventricular end-systolic volume index (RVESVI), and right ventricular ejection fraction (RVEF) were 98 ml/m², 38 ml/m² and 0.61, respectively.

The right-to-left ventricular end-diastolic volume ratio (RVEDV/LVEDV) was 0.74. The right-to-left ventricular end-systolic volume ratio (RVESV/LVESV) was 0.56. Left ventricular volume was larger than right ventricular volume both in diastole and in systole.

Left and right ventricular contraction were visualized from biplane cineangiograms (figs. 2

### Table 1. Postoperative Cardiac Catheterization Data

<table>
<thead>
<tr>
<th></th>
<th>PAP (mm Hg)</th>
<th>RVP (mm Hg)</th>
<th>RAP (mm Hg)</th>
<th>LVP (mm Hg)</th>
<th>AoP (mm Hg)</th>
<th>RVP/LVP</th>
<th>CI (l/min/m²)</th>
<th>SVI (ml/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First case</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First study</td>
<td>18/5 (12)</td>
<td>27/4 (3)</td>
<td>102/4</td>
<td>108/52 (80)</td>
<td>0.26</td>
<td>5.40</td>
<td>60.4</td>
<td></td>
</tr>
<tr>
<td>Second study at rest</td>
<td>32/10 (17)</td>
<td>30/5 (5)</td>
<td>102/8</td>
<td>120/68 (82)</td>
<td>0.29</td>
<td>3.58</td>
<td>48.4</td>
<td></td>
</tr>
<tr>
<td>During exercise</td>
<td>42/12 (24)</td>
<td>30/8 (8)</td>
<td>122/12</td>
<td>128/68 (92)</td>
<td>0.41</td>
<td>6.70</td>
<td>55.8</td>
<td></td>
</tr>
<tr>
<td><strong>Second case</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At rest</td>
<td>44/14 (24)</td>
<td>48/6 (4)</td>
<td>112/8</td>
<td>118/80 (96)</td>
<td>0.43</td>
<td>3.94</td>
<td>42.9</td>
<td></td>
</tr>
<tr>
<td>During exercise</td>
<td>62/26 (34)</td>
<td>66/4 (4)</td>
<td>140/4</td>
<td>140/84 (103)</td>
<td>0.47</td>
<td>4.43</td>
<td>33.5</td>
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</tr>
</tbody>
</table>

Abbreviations: PAP = pulmonary arterial pressure; RVP = right ventricular pressure; RAP = right atrial pressure; LVP = left ventricular pressure; AoP = aortic pressure; RVP/LVP = right-to-left ventricular pressure ratio; CI = cardiac index; SVI = stroke volume index measured by dye-dilution method.

### Table 2. Ventricular Volume Measured by Cineangiography

<table>
<thead>
<tr>
<th></th>
<th>LV (ml)</th>
<th>RV (ml)</th>
<th>RV/LV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First case</strong></td>
<td></td>
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</tr>
<tr>
<td>EDVI</td>
<td>133</td>
<td>98</td>
<td>0.74</td>
</tr>
<tr>
<td>ESVI</td>
<td>67</td>
<td>38</td>
<td>0.56</td>
</tr>
<tr>
<td>SVI</td>
<td>66</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>EF</td>
<td>0.50</td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td><strong>Second case</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDVI</td>
<td>139</td>
<td>93</td>
<td>0.67</td>
</tr>
<tr>
<td>ESVI</td>
<td>96</td>
<td>47</td>
<td>0.50</td>
</tr>
<tr>
<td>SVI</td>
<td>43</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>EF</td>
<td>0.31</td>
<td>0.49</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: LV = left ventricle; RV = right ventricle; RV/LV = right-to-left ventricular volume ratio; EDVI = end-diastolic volume index; ESVI = end-systolic volume index; SVI = stroke volume index; EF = ejection fraction.
Ventricular contraction appeared to be centripetal. A tangential projection of the prosthetic septum showed that it shifted 7 mm toward the right ventricle during systole.

Case 2

A 6-year-old boy was admitted to the Osaka University Hospital with a chief complaint of mild cyanosis. Details of this patient have been reported previously. Cardiac catheterization revealed pulmonary hypertension equal to systemic blood pressure and bidirectional shunts, with a pulmonary-to-systemic flow ratio (Qp/Qs) of 2.84. Angiocardiograms showed an anteriorly placed aorta, a posteriorly placed pulmonary artery and transposition of the great arteries with a ventricular septal defect. Total

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**Figure 2.** Case 1. Left ventriculograms. A and B show the diastolic phase. C and D show the systolic phase. A and C are right anterior oblique projections; B and D are left anterior oblique projections. A and C show good contraction of the left ventricle.
repair was undertaken in February 1975. When the pericardium was opened, it was found that the aorta was left and anterior and the pulmonary artery was right and posterior. The patient was placed on cardiopulmonary bypass and the ventricle was opened. There was no interventricular septum. The tricuspid and mitral valves were side by side and the mitral valve was posterior to tricuspid valve. A ventricular septum was created using a spiral Teflon patch, directing the blood flow through the tricuspid valve into the pulmonary artery and through the mitral valve into the aorta. The postoperative course has been uneventful. Three years and 1 month after surgery, the patient is leading an active life and taking no medications.

Postoperative study

Postoperative studies were performed in April 1975 and March 1978. The first postoperative study revealed a residual left-to-right shunt with a Qp/Qs of

![Image of ventriculograms]

**Figure 3.** Case 1. Right ventriculograms. A and B show the diastolic phase; C and D show the systolic phase. B and D were viewed from tangential projection to the prosthetic septum in A and C. A and C showed the shift of the prosthetic septum to the right ventricle in systole.
The data from the second study are as follows: Chest x-ray showed a cardiothoracic ratio of 0.62 (fig. 4). The ECG revealed left-axis deviation with a mean QRS (axis) of $-85^\circ$. Cardiac catheterization data are summarized in table 1.

Cardiac output and ventricular pressures were within normal range and no shunt was found. Cardiac output, measured by the dye-dilution method in the supine position, was poor during bicycle ergometer exercise with loading of 25 W over 5 minutes. Cardiac index increased from 3.94 at rest to 4.43 $1/min/m^2$ during exercise; stroke volume decreased. LVEDP decreased from 8 mm Hg at rest to 4 mm Hg during exercise. Right-to-left ventricular systolic pressure ratios were 0.43 at rest and 0.47 during exercise.

Angiocardiographic finding data are summarized in table 2. Left and right ventriculograms were obtained by biplane cineangiography. The shapes of left and right ventricles were somewhat different from the ventricles of the first patient due to the spiral patch ventricular septation (figs. 5 and 6). Left and right ventricular volumes were calculated from biplane cineangiograms. LVEDVI was 139 ml/m$^2$ and left ventricular stroke volume index (LVSVI) was 43 ml/m$^2$. RVEDVI and right ventricular stroke volume index (RVSVI) were 93 and 46 ml/m$^2$, respectively. LVEF and RVEF were 0.31 and 0.49, respectively. Right-to-left ventricular volume ratios were 0.67 in end-diastole and 0.50 in end-systole. The prosthetic septum shifted 9 mm toward the right ventricle during systole (fig. 6).

**Discussion**

Half of the patients with single ventricle had a smaller ventricular volume than the sum of the normal left and right ventricular volumes in our study. Ventricular volume in these 17 patients ranged from 71–200% of the sum of the normal left and right ventricular volumes. Feasibility of ventricular septation of single ventricle depends not only on the associated anomalies, but also on the ventricular cavity volume. Septation of a small ventricular cavity would result in a small stroke volume and cardiac output inadequate to support life even if the heart rate were to increase. Therefore, it is necessary for a single ventricle to have a larger volume than the sum of the normal left and right ventricular volumes. In our cases, preoperative ventricular cavity volume measurements were not made. It is important, however, to analyze the postoperative ventricular cavity volume characteristics to assess postoperative ventricular function and to apply the postoperative results to future preoperative management.

A report concerning ventricular volume estimation demonstrated that the geometric configuration of the chamber was indeed not critical, but the planar surface areas were very important. Left ventricular images of left and right oblique projections in figures 2 and 4 had silhouettes similar to those of the normal left ventricle. Moreover, right ventricular stroke volume was identical to left ventricular stroke volume and these values were almost identical to that measured by the dye-dilution method in the second patient, who underwent septation with a spiral patch. Therefore, the ventricular volume data were considered adequate to assess ventricular volume and function in patients with single ventricle.

In the first patient, total end-diastolic ventricular volume (LVEDVI + RVEDVI) was 231 ml/m$^2$, which is equal to 136% of the sum of the normal values of the left and right ventricles estimated by the formula described by Nakazawa et al. Total end-systolic volume was 105 ml/m$^2$ and the ejection fraction was 0.55, similar to those reported in other postoperative cyanotic heart diseases and to preoperative values in single ventricle. In the second patient, total end-diastolic ventricular volume was 166% of the sum of the normal left and right ventricular volumes. Total end-systolic volume was 140 ml/m$^2$ and the ejection fraction was 0.38, indicating depressed ventricular function. The cause of this depressed function is not clear. The total ventricular volumes of these two patients were greater than normal.

Inappropriate division of single ventricular volume would also make total stroke output lower than it would be after appropriate septation, when preoperative ventricular volume was identical. Therefore, a larger total ventricular volume than normal and an appropriate ventricular volume ratio of right to left ventricle are necessary for successful septation of single ventricle.

Contraction of single ventricle appears centripetal in systole and centrifugal in diastole. Ventricular contraction after septation generally showed movement similar to that of single ventricle before septation. The bulging of the prosthetic septum resulted in the

**Figure 4.** Case 2. Postoperative chest x-ray shows a cardiothoracic ratio of 0.62.
RVESV that was smaller than that of the left. Since the right ventricular stroke volume is normally almost the same as left ventricular stroke volume, the bulging of the septum causes the LVEDV to be greater than the right. In the first patient, right-to-left ventricular volume ratios (RVV/LVV) were 0.74 at the end-diastole and 0.56 at end-systole. They were 0.67 and 0.50, respectively, in the second patient. These results confirmed our opinion that single ventricle should be separated into a smaller right ventricle and larger left ventricle. Right-to-left ventricular cavity volume ratios were approximately 3:4 to 2:3 during diastole in our patients.

In addition to affecting ventricular volume, the paradoxical movement of the prosthetic septum reduces the LVEF. The right ventricular contraction is augmented due to shift of the patch toward the right

**Figure 5.** Case 2. Bidirectional left ventriculograms. A and B show the diastolic phase; C and D show the systolic phase. A and C are in the right anterior oblique projection; B and D are in the left anterior oblique projection.
ventricle. Therefore, RVEF is larger than LVEF. The right-to-left ventricular peak pressure ratios were 0.29 in the first patient and 0.43 in the second. If the ventricular pressures were equal, the prosthetic septum would probably not shift and the ventricular cavity volumes and ejection fractions would be the same in both ventricles. If ventricular septation results in the right ventricular cavity being smaller than the left, the peak right ventricular pressure must be less than the left postoperatively. The size of the prosthetic septum is related to left ventricular function because the paradoxical movement is decreased and the noncontractile area is reduced in the small patch. Therefore, a smaller patch is convenient to left ventricular function.

Cardiac output responses to exercise were excellent in the first patient. LVEDP increased to 12 mm Hg during exercise and the RVEDP increased to 8 mm Hg. In postoperative patients with ventricular septal defect who had normal responses to exercise with the same loading as these patients, LVEDP and RVEDP have never been reported to have increased during exercise. In the first patient, the increases of LVEDP and RVEDP during exercise were slightly abnormal. In the second patient, cardiac output increased a little, with a decrease in stroke volume during exercise. His

Figure 6. Case 2. Right ventriculograms. A and B show the diastolic phase; C and D show the systolic phase. A and C were viewed from the anteroposterior projection; B and D were from the lateral projections. B and D show the shift of the prosthetic septum to the right ventricle in systole.
exercise was a loading of 25 W over 5 minutes because he was small. LVEDP and RVEDP decreased during exercise, but a low ejection fraction and poor cardiac output response to exercise revealed poor ventricular function. Low ejection fraction and poor responses to exercise were considered due either to depressed myocardial contraction and/or to septation with a spiral patch.

References
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