VENTRICULAR VOLUME OF SINGLE VENTRICLE WITH OR WITHOUT PALLIATION AND AFTER CORRECTIVE SURGERY

—Concept of Septation Procedure—

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Ventricular volume measurements of single ventricle were carried out in 20 patients with or without palliation and in 2 after total correction. In the former 20 patients, 6 had a single left ventricle and 14 a single right ventricle, anatomically. Two having total correction were associated with undivided ventricle.

In the 20 patients with or without palliation, ventricular end-diastolic volume ranged from 64 to 206 (115 ± 42) percent of the sum of the normal left and right ventricular volumes. Ejection fraction of single ventricle ranged from 0.40 to 0.64 (0.55 ± 0.06). There was no significant difference in ventricular volume and ejection fraction between patients with a single left and right ventricle. There was high correlation of ventricular volume with pulmonary to systemic blood flow ratio (r = 0.66, p < 0.005). This indicates that systemic-to-pulmonary shunt should increase ventricular volume of single ventricle.

In two patients after total correction, total ventricular volume was 136, and 166% of the sum of the normal left and right ventricular volumes. Total ejection fraction was 0.55 and 0.33 in the first and second patient, respectively. The prosthetic ventricular septum bulged toward the right ventricle during systole and this shift made the left ventricular volume increase and ejection fraction decrease. Right-to-left ventricular volume ratio at end-diastole was 0.74 and 0.67 in the first and second patient, respectively.

These results suggest that 1) larger ventricular volume than the sum of the normal left and right ventricular volumes would be required for septation of single ventricle, 2) systemic-to-pulmonary shunts would be effective to increase ventricular volume of single ventricle, and 3) single ventricles should be divided into two to make a larger left and a smaller right ventricle, in cases where the right ventricular pressure is lower than the left after septation.

Key Words:
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ventricle into two (ventricular septation). The modified Fontan procedure imposes many restrictions in order to obtain a successful outcome. Also postoperative studies of the Fontan procedure indicate reduced exercise tolerance and less than normal cardiac output response to exercise. Ventricular septation has resulted in good exercise tolerance in patients with good ventricular function. Since a small main ventricle is an incremental risk factor in septation of the single ventricle ventricular volume studies are necessary to determine which procedure is appropriate.

In this study, we analyzed ventricular volume in patients with a single ventricle with or without palliation and after corrective surgery, and thus offer our concept about septation procedures from ventricular volume studies.

PATIENTS

Twenty patients with diagnoses of single ventricle, confirmed by cineangiography, and two patients with post ventricular septation were studied at the Osaka University Hospital. Single ventricle was defined as one ventricular chamber that received inflow of blood from both atrioventricular valves either separately or through a common atrioventricular valve. Cases associated with tricuspid atresia or mitral atresia were excluded. Our classification system was based on angiographic criteria matching the pathologic classification of Van Praagh et al. and Kozuka et al. The three anatomic groups are: (1) single left ventricle (type A according to Van Praagh’s classification); (2) single right ventricle (type B and D); and undivided (type C) ventricle, according to Kozuka et al. Of 20 patients with or without palliation 6 had single left ventricle and 14 had single right ventricle. Two patients after septation had an undivided ventricles.

Of the 8 patients with palliative surgery, six had undergone a systemic-to-pulmonary shunt operation and two a superior vena cava-to-pulmonary artery shunt. The 12 patients without any surgical procedure were separated into two groups, six with severe pulmonary stenosis or pulmonary atresia and six with only mild or no pulmonary stenosis. Ages of the 20 patients with single ventricle at the time of study ranged from 9 months to 14 years and averaged 4 ± 4 years (mean ± standard deviation). Arterial oxygen saturation ranged from 68 to 87 (79 ± 5) percent. Cardio-thoracic ratio ranged from 41 to 69 (56 ± 8) percent. Six patients had common atrioventricular valvar regurgitation. The ages of the two postsurgical patients at the time of study were 16 and 9 years. Ventricular septum had been made with a straight patch in the first patient and a spiral patch in the second.

METHODS

Ventricular cavity volumes were calculated from biplane cineangiograms after injections of contrast medium into the single ventricles of the 20 patients with or without palliation and into the right and left ventricles of the 20 post correction patients. Ectopic and postectopic beats were excluded from analysis. In most patients, the main chamber of the single left ventricle had a shape similar to that of the normal left ventricle, and biplane ventricular images of the single right ventricle were much the same as those seen in the normal right ventricle. Therefore, in the 20 patients with or without palliation, regression equation were applicable: \[ V_t = 0.93X V_c - 3.8 \text{ (ml)} \] for volume estimation of the single left ventricle, and \[ V_t = 0.76X V_c - 0.2 \text{ (ml)} \] for volume estimation of the single right ventricle, where \( V_t \) and \( V_c \) are true and calculated volume, respectively. The outlet chamber was not included in volume estimation of the single left ventricle.

In the two patients after septation, left and right ventricular volumes were calculated from left and right ventriculography, respectively. Ventricular volumes were also estimated from cineangiograms with the same methods as used in the 20 patients.

RESULTS

Ventricular volume in the 20 patients with or without palliation

End-diastolic volume ranged from 64 to 206 (115 ± 42) percent of the sum of the normal left and right ventricular end-diastolic volume estimated from the formula presented by Nakazawa et al. It averaged 111 ± 48 and 117 ± 41 percent in the single left and right ventricle, respectively. Ventricular end-diastolic volume averaged 137 ± 28 percent of the sum of the normal left and right ventricular end-diastolic volumes in 6 patients with only mild or no pulmonary stenosis and 135 ± 54 percent of the normal in 6 patients.
TABLE I  END-DIASTOLIC VOLUME TO THE SUM OF THE NORMAL LEFT AND RIGHT VENTRICULAR VOLUMES RATIO (PERCENT) AND EJECTION FRACTION IN THE THREE GROUPS

<table>
<thead>
<tr>
<th>Group</th>
<th>With only mild or no PS</th>
<th>With severe PS or PA</th>
<th>After systemic to pulmonary shunt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventricular Volume (%)</td>
<td>137 ± 28**</td>
<td>82 ± 15</td>
<td>135 ± 54*</td>
</tr>
<tr>
<td>Ejection fraction</td>
<td>0.58 ± 0.05</td>
<td>0.58 ± 0.04</td>
<td>0.51 ± 0.08</td>
</tr>
</tbody>
</table>

Ventricular volume was expressed as a percent of the sum of the normal left and right ventricular volumes estimated from the formula presented by Nakazawa et al.
PS = pulmonary stenosis; PA = pulmonary atresia
* = p < 0.05 vs group with severe PS or PA; ** = p < 0.002 vs group with severe PS or PA

after systemic to pulmonary shunt. Volume averaged 82 ± 15 percent of the normal in 6 patients with severe pulmonary stenosis or pulmonary atresia, and was significantly larger in 6 patients with only mild or no pulmonary stenosis (p < 0.002) or in 6 receiving systemic-to-pulmonary shunt (p < 0.05) (Table I). There was a high correlation between pulmonary to systemic blood flow ratio and the ventricular end-diastolic volume (r = 0.66, p < 0.005) (Fig. 1).

Ejection fractions in the 20 patients with or without palliation
Ejection fractions ranged from 0.40 to 0.64 (0.55 ± 0.06), averaging 0.56 ± 0.03 and 0.54 ± 0.08 in the single left and right ventricle, respectively. Ejection fraction averaged 0.58 ± 0.05 in 6 patients with only mild or no pulmonary stenosis, 0.58 ± 0.04 in 6 patients with severe pulmonary stenosis or pulmonary atresia and 0.51 ± 0.08 in 6 patients receiving systemic-to-pulmonary shunt. There was no significant difference (Table I) between these three groups. Ejection fraction averaged 0.57 ± 0.04 in 13 patients without atrioventricular regurgitation and was 0.49 ± 0.08 in 6 patients with incompetence (p < 0.01).

Ventricular volume in the two patients after total correction
Total ventricular volume was 136 and 166 percent of the sum of the normal left and right ventricular end-diastolic volumes in the first and

| Table II  VENTRICULAR VOLUMES IN THE TWO PATIENTS AFTER VENTRICULAR SEPTATION |
|----------|----------------|-----------------|----------------|------------|
|         | LV   | RV       | LV + RV (%) | RV/LV     |
| First cases |
| EDVI   | 133  | 98      | 231 (136)   | 0.74       |
| EF     | 0.50 | 0.61    | 0.55         |
| Second case |
| EDVI   | 139  | 98      | 232 (166)   | 0.67       |
| EF     | 0.31 | 0.49    | 0.38         |

LV = left ventricle; RV = right ventricle; % = percent of the sum of the normal left and right ventricular volumes; RV/LV = right to left ventricular volume ratio; EDVI = end-diastolic volume index (ml/m²); EF = ejection fraction.

Fig. 1. Relationship between pulmonary to systemic blood flow ratio (Qp/Qs) and end-diastolic volume to the sum of the normal left and right ventricular volumes ratio (percent). There was high correlation between them.

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second patient, respectively. The right-to-left ventricular volume ratio was 0.74 and 0.67. The prosthetic ventricular septum bulged toward the right-sided ventricle where systolic pressure was lower than was the left-sided ventricle in both patients. Ejection fractions of the left and the right ventricle were 0.50 and 0.61 in the first, and 0.31 and 0.49 in the second patient, respectively (Table II).

DISCUSSION

The feasibility of ventricular septation is dependent not only on the morphology of the main ventricle and associated anomalies, but also on the ventricular cavity volume. The right dominant type of single ventricle is not an indication for septation, because of the difficulty of dividing of it into two. The patient with a common atrioventricular valve is not a candidate for septation except where the single ventricle is of the undivided ventricle type. Ventricular cavity volume of the single ventricle depends upon the systemic and pulmonary blood flow elected by the ventricle.

This study demonstrated that a high correlation exists between the ventricular volume and pulmonary to systemic blood flow ratio, which indicates that systemic-to-pulmonary shunts should increase the ventricular volume of the single ventricle. The ejection fraction of the single ventricle was lower in patients with atrioventricular valve regurgitation than in those without incompetence (p < 0.01). This disorder suggested a more depressed ventricular function.

After establishing of right-sided atrium-to-pulmonary artery connection (modified Fontan procedure), the single ventricle has to sustain only systemic circulation. If the ejection fraction of the normal left ventricle is 0.65 and that of the single ventricle is 0.55, ventricular volume of

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**TABLE III**

<table>
<thead>
<tr>
<th>Postop. EF</th>
<th>EDV (% of the normal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.65</td>
<td>100%</td>
</tr>
<tr>
<td>0.60</td>
<td>108</td>
</tr>
<tr>
<td>0.55</td>
<td>118</td>
</tr>
<tr>
<td>0.50</td>
<td>130</td>
</tr>
<tr>
<td>0.45</td>
<td>144</td>
</tr>
<tr>
<td>0.40</td>
<td>163</td>
</tr>
<tr>
<td>0.35</td>
<td>186</td>
</tr>
</tbody>
</table>

First case

| 0.55       | 136%                  |

Second case

| 0.38       | 166%                  |

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*Fig.2. Schema of ventricular septation. (see text)*

RVP = right ventricular systolic pressure; LVP = left ventricular systolic pressure; RVV = right ventricular end-diastolic volume; LVV = left ventricular end-diastolic volume

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the single ventricle more than 0.65/0.55 (118%) of the normal left ventricle is adequate to obtain a normal stroke volume after the modified Fontan procedure. This study demonstrated that ventricular volume of the single ventricle was more than 130% of the normal left ventricular volume. This indicates that the single ventricle should have a sufficient ventricular volume for modified Fontan procedure.

Single ventricle has to sustain both systemic and pulmonary circulations after septation. If the ejection fraction of the normal ventricle (an average of left and right ventricular ejection fraction) is 0.65 and ejection fraction of the single ventricle is 0.55, ventricular volume of the single ventricle more than 0.65/0.55 (118%) of the sum of the normal left and right ventricular volumes would be sufficient to obtain a normal stroke volume and an adequate cardiac output under ordinary heart rate after septation. This value is dependent on the postoperative ventricular pump function (ejection fraction) of the total (left and right) ventricle, as presented in Table III. Table III shows that the ventricle with postoperative total ejection fraction of 0.55 would need 118% of the sum of the normal left and right ventricular volumes, and that with 0.40 would require 163% of the normal under ordinary heart rate. These predictions coincided with the data from the two post ventricular septation patients. The ejection fraction of the single ventricle after corrective surgery would be less than or the equal to the preoperative one, even when pulmonic ventricular pressure significantly decreased. Because, the non-contractile septum is not conducive to pump function of high pressure ventricle and operative procedure would reduce the ventricular pump function. Patients with lower ejection fractions require larger ventricular volume for ventricular septation. Therefore, it is important not only to estimate the volume, but also to calculate the ejection fraction of the single ventricle prior to septation.

Appropriate septation would support this prediction. If the prosthetic ventricular septum is attached at the center of the ventricular cavity and the right ventricular pressure is the same as the left, it would not bulge toward any other side of the ventricle, and ventricular volume and ejection fraction would then be same in both left and right ventricle. However, if the left ventricular pressure is higher than the right and the ventricular septum is centered on the ventricle at end-diastole, the ventricular septum will bulge toward the right during systole and the stroke volume of the right ventricle will exceed the left, as shown Fig. 2. Therefore, the ventricle should be divided to make a larger left and a smaller right ventricle. To make the right ventricle too small would result in a right ventricular stroke volume that is smaller than the left. Stroke volume after septation depends upon smaller stroke volume between the right and left ventricle. Unfortunately, we do not know as yet what proportion of the right and left ventricular volume is the most appropriate for septation.

There are two factors that affect ventricular pump function. The one is ventricular septum which does not have contractile force, and the other one is contraction of the ventricular free wall. In the first post operative case, the total ejection fraction was 0.55, which was the same as the mean value of that of the preoperative patients, and an appropriate septation might be done. Right-to-left ventricular volume ratio was 0.74 at end-diastole. In the second patient, the total ejection fraction was low value of 0.38. Causes of this low ejection fraction are suspected to be due to 1) reduced ventricular pump function, 2) the spiral patch used or 3) inappropriate septation. We did not clarify which is the true cause of the reduction in ventricular pump function in the second patient. It is hoped that this will be determined in the future.

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