The Early and Late Effects of Surgical Closure of Ventricular Septal Defects on Pulmonary Vascular Dynamics

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Closure of the ventricular septal defect (VSD) is one of the most common procedures in cardiac surgery. The result of this operation has been much improved in this decade. At present, fatality after closure of a VSD is very seldom encountered in most cardiac centers.

However, the pathophysiology of the surgically closed VSD is not always normalized after surgery. The subject to be discussed is, therefore, not only surgical mortality but also recovery to normal circulation after surgery. Practically to say, the pulmonary circulation is often non-physiologic after a VSD closure due either to anatomical or to functional change in the pulmonary vascular bed lasting after surgery.

The purposes of the present report are to investigate the late hemodynamic results in pulmonary circulation after the closure of VSD and to discuss the optimum age at which patients should undergo surgery based on the results obtained.

Materials and Methods

Sixty patients who underwent ventricular septal defect closure between 1959 and 1973 in Osaka University Hospital are the body of this investigation. Thirty-one males and 29 females in this series ranged in age from 6 months to 25 years (average 6 years and 5 months).

All patients underwent cardiac catheterizations before and after the closure of the VSD. Pressures in cardiac chambers and great vessels were also measured immediately after closure of the VSD during surgery. The intervals between surgery and postoperative cardiac catheterization were from 1 month to 8 years with an average of 1 year and 4 months.

From the results of cardiac catheterization, these patients were classified into 5 groups according to the classification described by Nakada1 as shown in Table I. Groups A and B are the patients with normal pulmonary vascular resistance. Groups C, D, and E are the patients with increased pulmonary vascular resistance. These 60 patients were also divided into 3 groups according to age at the time of surgery. No patient in group B underwent surgery at or before age 2. There was only one patient in Group E.

Results

The average of pulmonary arterial mean pressure (PAm), pulmonary artery to systemic artery systolic pressure ratio (Pp/Ps) and pulmonary vascular resistance to systemic vascular resistance ratio (Rp/Rs) of the respective groups of patients were measured and calculated before operation, immediately after closure of VSD, and late after operation as shown in Fig. 1. The average of PAm in Group A patients was slightly higher than the normal range before operation and came down to the normal range immediately after surgery. PAm in Group B patients was within the normal range both before and after surgery. PAm in Group C, D, and E patients fell significantly immediately after closure of VSD. However, only the average of PAm in Group C patients was within the normal range immediately after surgery. Even at the time of late postoperative study, the PAm in many patients in these groups of patients still remained above normal.
TABLE I PATIENTS SUBJECTED TO CLOSURE OF VENTRICULAR SEPTAL DEFECT AND PRE- AND POSTOPERATIVE CARDiac CATHETERIZATIONS

<table>
<thead>
<tr>
<th>Group</th>
<th>Patients</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rp/Rs</td>
<td>2yr</td>
<td>3–4yr</td>
<td>-5yr</td>
<td>Total</td>
</tr>
<tr>
<td>A</td>
<td>Rp/Rs &lt; 0.15, Qp/Qs ≥ 1.80</td>
<td>7</td>
<td>1</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>B</td>
<td>Rp/Rs ≤ 0.15, Qp/Qs &lt; 1.80</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>C</td>
<td>0.15 ≤ Rp/Rs &lt; 0.50</td>
<td>6</td>
<td>6</td>
<td>13</td>
<td>25</td>
</tr>
<tr>
<td>D</td>
<td>0.50 ≤ Rp/Rs &lt; 0.85</td>
<td>7</td>
<td>1</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>E</td>
<td>0.85 ≤ Rp/Rs</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td>20</td>
<td>12</td>
<td>28</td>
<td>60</td>
</tr>
</tbody>
</table>

\[ \frac{Rp}{Rs} = \frac{\text{pulmonary vascular resistance}}{\text{systemic vascular resistance}}, \quad \frac{Qp}{Qs} = \frac{\text{pulmonary blood flow}}{\text{systemic blood flow}} \]

CHANGES OF PAm, Pr/Ps & Rp/Rs (ALL CASES)

Fig.1. The change of pulmonary arterial mean pressure (PAm), pulmonary artery to systemic artery systolic pressure ratio (Pp/Ps), and pulmonary vascular resistance to systemic vascular resistance ratio (Rp/Rs) according to the hemodynamic group (A to E; see text).

the normal range.

Ps/Ps in Group A and B patients were mostly within the normal range throughout the course. The decreases of Pp/Ps immediately after closure of VSD were remarkable both in Groups C and D but not in one patient in Group E. Further, a slight decrease of Pp/Ps was noted in Group C and D patients at late postoperative study. Pp/Ps in the Group E patient also decreased to the normal range at this time.

Rp/Rs in Group A and B patients were within the normal range both before and after surgery. The decrease in Rp/Rs immediately after closure of the VSD was significant in Group D and E.

patients and was less significant in Group C patients. Late after surgery, a further decrease in Rp/Rs was found in all three groups of patient with preoperative high pulmonary vascular resistance, particularly in Group D and E patients.

The change in PAm was investigated according to the age at operation as shown in Fig. 2. In patients operated upon at 2 years of age or less, PAm decreased immediately after closure of the VSD to a normal range. Also in patients operated
upon from 3 to 4 years of age, the average of PAm normalized immediately after closure of the VSD except in the Group E patient. At the time of late catheterization, the PAm was within the normal range in all of them. Among the patients operated upon at 5 years of age or more, the average PAm in Group A decreased to the normal range immediately after closure of the VSD. The average PAm in Group B patients remained within the normal range before and after surgery. The average PAm in Group C patients decreased significantly immediately after closure of the VSD, but in many of them the PAm still remained above 25 mmHg. Even at the time of late catheterization, these values remained almost unchanged. In Group D patients also, the PAm decreased significantly immediately after closure of the VSD, but remained much higher than
25 mmHg in the majority of them. The average of PAm in this group of patients decreased slightly at the time of late catheterization, but still remained higher than the normal value.

The changes of Pp/Ps after closure of the VSD were shown in Fig. 3 according to age groups. In patients operated upon at 2 years of age or less, the average of Pp/Ps in Group A remained within the normal range before and after surgery. In Group C and D patients, the averages of Pp/Ps significantly decreased immediately after surgery to the normal range. Further, slight decreases were found at the time of late catheterization, but the difference were not significant. In patients operated upon from 3 to 4 years of age, the average of Pp/Ps in Group B was within the normal range before and after surgery. The Pp/Ps in a Group A patient and in a Group D patient, and the average of Pp/Ps in Group C patients decreased significantly to the normal range immediately after closure of the VSD. Further changes in these values at the time of late catheterization were not significant. The Pp/Ps in a Group E patient decreased immediately after closure of the VSD but remained high and normalized at the time of late catheterization. In patients operated upon at 5 years of age or more, the average of Pp/Ps in Group B remained within the normal range before and after operation. The average of Pp/Ps in Group A patients decrease immediately after surgery and normalized. Both in Group C and D patients, the average of Pp/Ps decreased significantly immediately after closure of the VSD. The average in Group C patients normalized but that in Group D patient did no. At the time of late catheterization, further slight and mild decreases were found in the averages of Pp/Ps of these two groups of patients respectively. These values were 0.33 and 0.41 respectively.

The change of Rp/Rs after closure of the VSD was also investigated according to the age at operation. When operated upon at 2 years of age or less, the average of Rp/Rs in all hemodynamic groups of patients decreased to less than 0.15 immediately after closure of the VSD as shown in Fig. 4. In patients operated upon at the age of 3 or 4, Rp/Rs in groups C, D and E, decreased immediately after closure of the VSD but mostly remained higher than 0.15. Further decrease in this value was noted at the time of late catheterization, and in most of these patients Rp/Rs were less than 0.15. In patients operated upon at 5 years of age or more, the average of Rp/Rs in Group A and B remained less than 0.15 both before and after surgery. The average of Rp/Rs in Group C and D patients decreased moderately immediately after closure of the VSD but remained much higher than the normal value. Even at the time of late catheterization these ratios were still high in these groups of patients, 0.19 and 0.29, respectively, though there was some further decrease after surgery.

**DISCUSSION**

The closure of a VSD is a well established procedure for the correction of congenital cardiac anomaly. Pulmonary circulation after surgery, however, was not always normalized mostly because of non-reversible pathologic changes in the pulmonary vascular bed.

In most patients with normal pulmonary vascular resistance before surgery, the variables representing the pulmonary circulation normalized immediately after surgery. Those in patients with increased pulmonary vascular resistance before surgery significantly improved immediately after closure of the VSD but remained in the abnormal range in many of them. Further improvement were found at the time of late catheterization though these variables still remained in the abnormal range in some of them. In general, the value of these variables immediately after and late after closure of the VSD were much improved in patients with less increased pulmonary vascular resistance before surgery than those with more increased pulmonary vascular resistance.

Though this relationship was clearly demonstrated in Rp/Rs, there was wide variation in this ratio among the patients in respective groups. For this reason, the change of Rp/Rs before and late after surgery in patients with this ratio of more than 0.15 before surgery (Group C, D, and E patients) were plotted against the age at operation, and at late catheterization as shown in Fig. 5. It was clearly demonstrated that the Rp/Rs late after surgery was less than 0.15 in patients operated upon at 4 years of age or less. On the other hand, among the patients operated upon at 5 years of age or more, it was rare to have the Rp/Rs less than 0.15 late after surgery. The better hemodynamic results in pulmonary circulation after closure of the VSD in the younger group of patients were reported previously by many investigators.

In order to clarify the relationship between the change of pulmonary circulation after closure
of the VSD and the age at operation, the authors divided the patients into 3 age groups as reported above. It was clear that the variables in pulmonary circulation usually normalized immediately after closure of the VSD when operated upon at 2 years of age or less, irrespective of the hemodynamic condition of the pulmonary circulation before surgery. Even though the VSD was closed at 3 years of age or more, pulmonary circulation usually normalized in patients with normal pulmonary vascular resistance before surgery. When the patient with elevated pulmonary vascular resistance was operated upon at the age of 3 or 4, PAm, Pp/Ps and Rp/Rs significantly decreased immediately after surgery, but did not always normalize. These variables, however, normalized at the time of late catheterization. When the patients with high pulmonary vascular resistance were operated upon at 5 years of age or more, these variables mostly remained in the abnormal range immediately after closure of the VSD and even so in many of them at the time of late cardiac catheterization.

It is suggested from these findings that the increased pulmonary vascular resistance in patients at the age of 2 years or less is functional irrespective of its severity and reversible when excessive pulmonary blood flow was eliminated and the back pressure from the left side of the heart disappeared. Vasoconstrictive factors had been attributed to those in whom resistance was reversible immediately after closure of the VSD. In 3 or 4 year-old patients, the increased pulmonary vascular resistance seemed mainly functional and partly organic. The organic resistance, however, was considered to be reversible with time. In patients with the age of 5 years or more, the pulmonary vascular resistance seemed partly functional and mainly organic. Some of the resistance was irreversible even with time. The degree of the decrease in pulmonary vascular resistance after surgery may depend on the duration between the operation and late catheterization. On the other hand, however, there was a patient whose Rp/Rs actually increased after surgery as shown in Fig. 5.

From these findings and the low mortality rate of surgery at present, the authors recommend VSD closure the latest at 4 years of age when the pulmonary vascular resistance of the patient is elevated. Otherwise, the pulmonary circulatory dynamics after surgery may remain abnormal even with time. For the purpose of obtaining normal pulmonary circulation immediately after closure of the VSD, the patient with high pulmonary vascular resistance should undergo closure of the VSD at 2 years of age or less.

**Summary**

In sixty patients who underwent closure of ventricular septal defect (VSD), cardiac catheterizations were performed before and late after surgery together with pressure measurements immediately after closure of the VSD during surgery.

Pulmonary arterial mean pressure (PAm), pulmonary arterial systolic pressure to systemic arterial systolic pressure ratio (Pp/Ps), and pulmonary vascular resistance to systemic vascular resistance ratio (Rp/Rs) were measured and calculated. The patients were classified into 5 groups according to the preoperative Rp/Rs and Qp/Qs as was reported by Nakada: Group A: Rp/Rs < 0.15, Qp/Qs ≥ 1.8, Group B: Rp/Rs < 0.15, Qp/Qs < 1.8, Group C: 0.15 ≤ Rp/Rs < 0.50, Group D: 0.50 ≤ Rp/Rs < 0.85, Group E: 0.85 ≤ Rp/Rs. These groups were further divided into 3 groups respectively according to age at operation (< 2 years, 3 or 4 years, 5 years <).

The averages of PAm, Pp/Ps, and Rp/Rs were within the normal range in Group A and B patients (normal pulmonary vascular resistance groups) irrespective to the age at operation except the average of PAm before surgery. In Group C, D and E patients (elevated pulmonary vascular resistance group), these variables decreased immediately after closure of VSD, and further decreases were noted at the time of late catheterization. These variables, however, did not completely normalize even at that time.

Among the patients operated upon at 2 years of age or less, the averages of these variables normalized immediately after closure of the VSD. When operated upon at 3 or 4 years of age, these variables decreased but did not normalize immediately after closure of the VSD and were found to be within the normal range at the time of late catheterization. When operated upon at 5 years of age or more, these variables decreased immediately after closure of the VSD, and further decrease was found at the time of late catheterization but mostly remained in the abnormal range even at this time.

From the data obtained herein, the factors producing the pulmonary vascular resistances in respective age groups were discussed. The closure of VSD in patients with elevated pulmonary vascular resistance should be done at 2 years of age or less.
vascular resistance is recommended at the latest 4 years of age and preferably at 2 years of age or less, in order to obtain normal pulmonary circulatory dynamics after surgery.

REFERENCES


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