Primary Surgical Closure of Ventricular Septal Defect in the First Year of Life: Results in 128 Infants

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Between January 1973 and July 1981, 128 patients less than 1 year of age with failure to thrive, congestive heart failure or pulmonary artery hypertension underwent primary repair of a ventricular septal defect. The hospital mortality rate was 7.8% (10 of 128), and the late mortality rate was 2.3% (3 of 128). Mortality was highest among younger infants with preexisting respiratory problems or a hemodynamically significant residual lesion postoperatively. Complications included a large residual shunt in eight (6.2%), transient neurologic problems in five (3.9%) and persistent complete heart block in three (2.3%). Lung biopsy specimens obtained from 49 patients showed pulmonary vascular abnormalities in all. Complete right bundle branch block developed in 74 (64%) and bifascicular block appeared in 11 (9%).

Recatheterization in 70 patients (55%) showed normal pulmonary artery pressures in all but 2 patients with a large residual shunt. Complete closure of the defect had been achieved in 49 (70%) and a hemodynamically insignificant shunt remained in 19 (27%). Patients without significant hemodynamic residua were asymptomatic and tended to accelerate in growth after surgery.

Methods

Patients. The hospital records of all infants less than 1 year of age who underwent surgery for repair of a ventricular septal defect between January 1973 and July 1981 were reviewed. Patients with extracardiac anomalies were included, while those with a hemodynamically significant associated cardiac defect other than an atrial septal defect (3 infants) or a patent ductus arteriosus (19 infants) were excluded. During this 8 1/2 year period, 128 patients (69 girls and 59 boys) were identified who met these criteria.

The indications for surgery were failure to thrive, congestive heart failure or pulmonary artery hypertension. All but three of the patients were at or below the third percentile for weight at the time of surgery (Fig. 1).

Hemodynamic data. All of the patients underwent at least one preoperative catheterization, including right and left heart oxygen saturation and pressure measurements, measured oxygen consumption and a left ventricular cineangiogram to demonstrate the number and location of the ventricular septal defects. Oxygen saturation and pressure data from the immediate postoperative period were obtained in 101 patients through left atrial, right atrial, pulmonary and radial artery catheters that were placed during the operation and removed approximately 24 hours postoperatively. In some cases, pulmonary artery pressures were mea-
sured while the patient was receiving positive pressure ventilation.

Seventy patients (55%) underwent repeat catheterization between 3 days and 40 months (median 12 months) after operation.

Electrocardiography. All 128 patients had a 12 lead electrocardiogram obtained at the time of admission for surgery. One hundred-twenty patients (94%) had a second electrocardiogram recorded before discharge. Late follow-up electrocardiograms obtained at the time of repeat catheterization or outpatient clinic visit were available in 58 patients (45%).

Operative procedure. The technique of deep hypothermia and circulatory arrest was employed in 121 (95%) of the 128 patients. After the initiation of circulatory arrest, the right atrium was opened and the ventricular septum was inspected through the tricuspid valve. The ventricular septal defect was single in 111 (87%) of the patients (membranous in 99 [77%], subpulmonary in 6 [5%], atrioventricular canal type in 3 [2%] and muscular in 3 [2%]). In 17 patients (13%), there were multiple ventricular septal defects. In 113 patients (88%), the defect or defects were closed transatrially. In 15 patients (12%), either a left or right ventriculotomy was employed to close the defect or defects. Five patients, all with multiple ventricular septal defects, had a left ventriculotomy. Nine patients had a right ventriculotomy, including seven with subpulmonary defects, either singly or in combination with other defects. One patient who had a right ventriculotomy had a single membranous defect, and another had a membranous defect in combination with a muscular defect. One patient with a large muscular defect had both a right and left ventriculotomy.

All large ventricular septal defects were closed using a knitted Dacron patch secured with either interrupted, pledget reinforced sutures or a continuous suture. The duration of circulatory arrest ranged from 24 to 65 minutes (mean 38) and was somewhat longer in patients with multiple ventricular septal defects (mean 48 minutes). Small muscular defects were closed using simple pledged sutures.

Lung biopsy. Of the 85 infants undergoing ventricular septal defect closure from 1977 to 1981, 49 (58%) were randomly selected for lung biopsy collection. The tissue was obtained, fixed and stained according to the procedures outlined by Rabinovitch et al. (8). The specimens were then graded according to the classification of Heath and Edwards and the morphometric classification (8–11) (grade A: abnormal extension of muscle into the small peripheral arteries; grade B: increased thickness of the medial muscular coat in addition to muscle extension; grade C: a reduction in the ratio of small peripheral arteries to alveoli).

Follow-up. Among the survivors, postoperative information was available in 77 patients (66%). The duration of clinical follow-up ranged from 7 to 108 months (median 23). Growth data were obtained at the time of follow-up catheterization or at one of several postoperative clinic visits.

Results

Mortality. The hospital mortality rate among these infants was 7.8% (10 of 128). There were three known late deaths (2.3%), resulting in an overall mortality rate of 10% (13 of 128).

Preoperative causes of mortality. Preoperative respiratory problems appeared to be a contributory cause of death in four patients (Table I). One (Case 14) required preoperative intubation for pneumonia. A second infant (Case 117) with pneumonia also had a urinary tract infection and was treated with systemic antibiotics for 1 week before surgery. Despite the antibiotic therapy, postmortem cultures indicated generalized gram-negative sepsis. A third patient (Case 77) had multiple congenital anomalies and recurrent episodes of aspiration and died 44 days postoperatively after the development of an extensive aspiration pneumonia. A fourth infant (Case 66) had episodes of severe bronchospasm preoperatively and required chronic ventilatory support postoperatively. Laryngoscopy demonstrated laryngeal polyps that were successfully excised. Nonetheless, the patient became acutely stridorous 19 days postoperatively and died. None of the survivors required preoperative intubation and none were known to have preoperative pneumonia.

In two infants, preoperative errors in diagnosis may have contributed to mortality. One patient (Case 51) had multiple ventricular septal defects that were unsuspected preoperatively, requiring a second operation for a subpulmonary ventricular septal defect. The other patient (Case 57) had a double orifice mitral valve and small left ventricle that had not been recognized preoperatively.

Figure 1. Age and weight of patients at the time of surgery for primary closure of a ventricular septal defect. The solid line represents the third percentile for normal infants.
### Table 1. In-Hospital and Late Deaths After Closure of Ventricular Septal Defect

<table>
<thead>
<tr>
<th>Case</th>
<th>Age at Op (mo)</th>
<th>Year of Op</th>
<th>VSD Type</th>
<th>Closure</th>
<th>Time of Death Postop</th>
<th>Cardiac Anomalies</th>
<th>Noncardiac Anomalies</th>
<th>Comments</th>
</tr>
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<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1973</td>
<td>Membranous</td>
<td>TA</td>
<td>6 h</td>
<td>None</td>
<td>None</td>
<td>Severe pneumonia and pulmonary vein laceration, postoperative respiratory failure</td>
</tr>
<tr>
<td>14</td>
<td>2</td>
<td>1974</td>
<td>Membranous</td>
<td>TA</td>
<td>67 h</td>
<td>LSVC to CS, PPS</td>
<td>Noonan's syndrome</td>
<td>Severe pneumonia and pulmonary vein laceration, postoperative respiratory failure</td>
</tr>
<tr>
<td>15</td>
<td>2</td>
<td>1974</td>
<td>Membranous</td>
<td>TA</td>
<td>87 h</td>
<td>Vascular ring</td>
<td>None</td>
<td>Postoperative tachyarrhythmias and persistent low output</td>
</tr>
<tr>
<td>51</td>
<td>3</td>
<td>1977</td>
<td>Multiple</td>
<td>TA</td>
<td>26 h</td>
<td>None</td>
<td>Cleft palate</td>
<td>Reoperation for undiagnosed subpulmonary VSD, persistent low output after second operation</td>
</tr>
<tr>
<td>57</td>
<td>2</td>
<td>1977</td>
<td>Multiple</td>
<td>TA</td>
<td>21 h</td>
<td>None</td>
<td>None</td>
<td>Persistent low output, double orifice mitral valve and small left ventricle at autopsy</td>
</tr>
<tr>
<td>66</td>
<td>1</td>
<td>1978</td>
<td>Subpulmonary</td>
<td>TA</td>
<td>29 days</td>
<td>PDA</td>
<td>Laryngeal polyps</td>
<td>Severe bronchospasm and airway obstruction</td>
</tr>
<tr>
<td>68</td>
<td>9</td>
<td>1978</td>
<td>Membranous</td>
<td>TA</td>
<td>0 h</td>
<td>None</td>
<td>None</td>
<td>Death on operating table, inability to wean from CPB</td>
</tr>
<tr>
<td>71</td>
<td>1</td>
<td>1978</td>
<td>Subpulmonary</td>
<td>RV</td>
<td>23 h</td>
<td>None</td>
<td>Multiple orthopedic anomalies</td>
<td>Persistent low output</td>
</tr>
<tr>
<td>77</td>
<td>2</td>
<td>1978</td>
<td>Membranous</td>
<td>TA</td>
<td>44 days</td>
<td>PDA</td>
<td>None</td>
<td>Recurrent aspiration pneumonia</td>
</tr>
<tr>
<td>117</td>
<td>10</td>
<td>1981</td>
<td>Multiple</td>
<td>LV</td>
<td>43 h</td>
<td>Congenital CHB</td>
<td>None</td>
<td>Preoperative pneumonia and urinary tract infection, postmortem cultures indicated gram-negative sepsis</td>
</tr>
</tbody>
</table>

**Operative technical problems.** One infant (Case 2), who had required preoperative intubation for respiratory failure, suffered a laceration of a pulmonary vein at the time of left atrial line placement and underwent a right thoracotomy to achieve hemostasis. The patient was weaned from cardiopulmonary bypass with great difficulty, and low cardiac output resulted in death 6 hours postoperatively.

One patient (Case 15) had an uncontrollable junctional tachycardia with a heart rate of approximately 240 beats/min and died with low cardiac output 3 days after surgery. The remaining two infants appeared to be in relatively good health preoperatively and no technical difficulties were encountered intraoperatively. One patient (Case 68) could not be weaned from cardiopulmonary bypass, and the other (Case 71) died 23 hours postoperatively with persistent low cardiac output.

**Late deaths.** Three patients are known to have died after discharge from the hospital. Two of these deaths were sudden and unexpected, suggesting an arrhythmic event. One of these patients had electrocardiographic evidence of anterolateral myocardial fibrosis. The third late death occurred in a patient who developed a double chamber right ventricle.
and complete heart block 5 years after successful closure of her ventricular septal defect. She died at another institution during surgery to relieve the right ventricular outflow obstruction and implant a pacemaker.

Other factors affecting mortality. The mortality rate was 18% (3 of 17) for patients with multiple ventricular septal defects, 50% (3 of 6) for patients with a single subpulmonary ventricular septal defect and 8% (8 of 99) for patients with a single membranous ventricular septal defect. The hospital mortality rate for infants 4 months of age or less at the time of surgery was 19% (8 of 43). The mortality rate remained relatively constant throughout the duration of the study period. Neither preoperative hemodynamic measurements nor lung biopsy results were predictive of outcome for these infants.

Complications. Residual shunt. Eight patients (6%) had early postoperative clinical and laboratory evidence of a large residual left to right shunt and a second operation was undertaken. Three of these patients underwent pulmonary artery banding; in the other five the residual ventricular septal defect was closed without mortality. All three with banding have since undergone band removal and closure of a ventricular septal defect without incident.

Complete heart block. Ten patients (8%) had transient complete heart block that reverted to sinus rhythm within 1 week of surgery. Two patients (2%) had persistent complete heart block treated by permanent pacemaker insertion before discharge. One of the patients who had transient complete heart block after surgery developed late complete heart block several years after closure of the ventricular septal defect. Of the 10 patients who had transient complete heart block, 8 had a membranous ventricular septal defect and 2 had a muscular ventricular septal defect. Of the three patients who developed permanent complete heart block, all had a membranous ventricular septal defect and one had a muscular defect as well.

Myocardial infarction and supraventricular tachycardia. Two patients (2%) had electrocardiographic evidence of myocardial infarction in the early postoperative period, one of whom died suddenly 6 weeks postoperatively with autopsy-confirmed myocardial fibrosis. Seven patients (6%) experienced episodes of supraventricular tachycardia postoperatively.

Transient neurologic sequelae. These were recognized in five patients (4%). Three patients had generalized seizures postoperatively, one had a transient left hemiparesis and one had irritability and hypertonia. No patient had a persistent neurologic deficit that was not present before surgery.

Hemodynamic measurements and catheterization findings. Pulmonary artery pressure and pulmonary resistance. Preoperatively, the pulmonary artery pressure was elevated (mean pressure greater than 20 mm Hg) in 107 (96%) of the 111 infants in whom it was measured (Fig. 2). Of 101 patients with early postoperative measurements, 52 (51%) continued to have elevated pulmonary artery pressure. At a follow-up postoperative catheterization, 4 (8.5%) of 47 patients in whom measurements were available had elevated mean pulmonary artery pressure, 2 of whom had a value greater than 25 mm Hg. Both of these patients had a residual shunt with a pulmonary to systemic blood flow ratio greater than 2:1.

Of the 111 patients in whom preoperative pulmonary resistance was calculated, 32 (29%) had a value greater than 3.0 Wood units (Fig. 3). At follow-up repeat catheterization, 3 (6.3%) of 48 patients had elevated pulmonary resistance, 2 of whom were the patients with a large residual ventricular septal defect. The third patient had elevated pulmonary artery pressure and pulmonary resistance that became normal during breathing of 100% oxygen.

Intracardiac shunt. Preoperatively, of 125 patients whose measurements were available, 115 (92%) had a pulmonary to systemic blood flow ratio greater than 2:1. Of 70 patients who underwent repeat catheterization postoperatively, the ventricular septal defect was closed in 49 (70%). Nineteen (27%) had a small residual defect with a pulmonary to systemic blood flow ratio less than 1.5:1. Two patients (3%) had a residual shunt with a pulmonary to systemic blood flow ratio greater than 2:1 and both patients underwent subsequent repair.

Other intracardiac abnormalities. Three patients developed aortic regurgitation postoperatively. In two, the murmur of aortic regurgitation appeared immediately, while in the third, the murmur became audible several months after surgery. Angiographically, the aortic regurgitation was severe in one patient, and mild to moderate in the other two. Three patients had a double chamber right ventricle identified subsequent to ventricular septal defect closure.

Figure 2. Mean pulmonary artery (PA) pressures measured during the preoperative catheterization (PRE-OP), the early postoperative period (POST-OP) and the follow-up re catheterization (FOLLOW-UP). The circled points represent the two patients with a large residual ventricular septal defect who subsequently underwent reoperation. The solid lines represent the median of each group.
patients were found to have developed discrete subaortic stenosis with a peak systolic ejection gradient of 62 and 30 mm Hg, respectively. One has undergone resection of a subaortic membrane. Two patients were found to have coarctation of the aorta that had not been apparent preoperatively. One patient was found to have partial anomalous pulmonary venous return to the right atrium that was not recognized before the postoperative cardiac catheterization.

Electrocardiography. The most typical preoperative findings were right axis deviation in 61 patients (48%) and biventricular hypertrophy in 93 (73%). Twenty-two patients (17%) had a superior frontal plane axis preoperatively. One patient had congenital complete heart block.

Postoperatively, 74 (62%) of the patients demonstrated findings of complete right bundle branch block. Forty (33%) of the patients had a superior frontal plane axis postoperatively and 11 (9%) patients had evidence for bifascicular block (complete right bundle branch block and left axis deviation not present preoperatively). Eight patients had first degree atrioventricular (AV) block in the postoperative period. Two patients had complete heart block at the time of discharge and a third developed complete heart block late postoperatively.

Lung biopsy. Lung biopsy specimens were obtained from 49 (58%) of 85 patients operated on since 1977. Pulmonary vascular abnormalities were present in all tissue samples (Table 2). Thirty-two (65%) of the patients demonstrated grade IB changes, while an additional 14 patients (29%) showed a reduction in arterial number (grade C) with or without intimal proliferation (grade II). The calculated preoperative pulmonary resistance for patients found to have grade B changes (2.26 ± 1.77) was not significantly different from that in patients found to have grade C changes (3.04 ± 1.73). Of 11 patients with grade B changes who underwent repeat catheterization, one had an elevated pulmonary resistance and mildly elevated pulmonary artery pressure, both of which decreased with the patient breathing 100% oxygen. Four patients with grade C changes underwent repeat catheterization postoperatively and none had an elevated pulmonary resistance or pulmonary artery pressure.

Follow-up. Of the 77 patients for whom follow-up information was available, 1 patient (1.3%) had dyspnea on exertion and fatigue and was subsequently found to have a large residual ventricular septal defect. None of the remaining patients had any cardiovascular symptoms noted at their most recent follow-up visit. Six patients (7.8%) were receiving digoxin: one with aortic regurgitation, two with subaortic stenosis and three for unspecified indications.

There was a tendency for accelerated weight gain during the first 12 to 24 months after operation (Fig. 4). The rate of growth declined somewhat as the patients approached a normal distribution several years after surgery. Among the patients for whom follow-up was available, nine remained below the third percentile for weight beyond 18 months of age. Four of these patients had hemodynamically significant residua (severe aortic regurgitation, moderate subaortic stenosis, partial anomalous pulmonary venous return and a residual left to right shunt), one patient had multiple congenital anomalies including a tracheoesophageal fistula and one had severe mental and motor retardation recognized before operation. The remaining three children had no recognizable abnormalities.

Discussion

Mortality in younger versus older infants. Recent reviews of primary closure of a ventricular septal defect in infancy report a mortality rate of 2.4 to 24% (12–21). A consistently higher rate has been encountered among infants undergoing operation during the first few months of life. Although the mortality rate was higher among the younger patients in our experience as well, the circumstances surrounding the deaths must be emphasized. Intractable
Risk factors. The identification of clear and unequivocal risk factors is difficult in these infants. The presence of multiple ventricular septal defects appears to be associated with a higher mortality rate, possibly related to longer circulatory arrest time or the more frequent need for ventriculotomy. Subpulmonary ventricular septal defects may also be associated with a higher operative risk. The patient’s age at the time of surgery and other complicating factors such as respiratory failure or systemic infection are inextricably linked, so that the independent contribution of each to operative risk is impossible to determine. However, it is our impression that age by itself has relatively little influence on the outcome of surgery, although younger infants are often sicker and may be less tolerant of residual postoperative hemodynamic abnormalities.

Postoperative complications. The major early postoperative complication in this series (eight patients, 6%) was a significant residual ventricular septal defect, requiring either a second attempt at closure or the placement of a pulmonary artery band. Beyond the early postoperative period, only two patients (3%) were found to have a large residual ventricular septal defect at recatheterization, although approximately 25% of all patients studied had a small, hemodynamically insignificant residual defect. This almost certainly overestimates the incidence of residual defects because patients with a murmur would be more likely to have a postoperative catheterization.

Pulmonary artery pressure and resistance. Pulmonary artery hypertension was almost universally present preoperatively in this group of patients. Immediately after operation, approximately 50% of the patients monitored had normal pulmonary artery pressures. At follow-up catheterization, significant persistent pulmonary artery hypertension was demonstrated in only two patients, both of whom had a large residual defect. Similarly, calculated pulmonary resistance was abnormal at follow-up catheterization in three patients, two of whom were the patients with a residual shunt and pulmonary artery hypertension. These data confirm other reports (16,22) which suggest that the risk of developing irreversible pulmonary vascular changes in the first year of life, even in the presence of high pulmonary artery pressure and a large shunt, is very low in infants with one or more ventricular septal defects as their principal cardiac malformation.

Histologic pulmonary findings. Some histologic abnormalities were present in all patients from whom lung biopsy material was obtained. The most common findings were abnormal extension of muscle into the small peripheral arteries and an increase in the thickness of the medial muscle coat. These findings have been correlated with an increase in pulmonary artery pressure and pulmonary blood flow (23). Fourteen patients demonstrated a reduction in the number of small arteries (grade C), a finding Rabinovitch et al. (8) believed represented advanced lung disease. However,
no significant association between lung biopsy results and preoperative hemodynamic variables could be established in these patients. Four patients with grade C changes also underwent postoperative catheterization, and no hemodynamic abnormalities were present. These findings suggest that the morphometric technique for grading lung histology does not have strong predictive value for the assessment of hemodynamically apparent pulmonary vascular changes in infancy.

Role of postoperative cardiac catheterization. Follow-up catheterization was helpful in localizing and quantifying hemodynamic abnormalities in patients who had clinical evidence for a residual lesion. However, no patient had a major cardiac defect that was clinically unsuspected. This suggests that repeat postoperative cardiac catheterization studies may be reserved for those patients with abnormal physical or laboratory findings.

Postoperative conduction defects. Persistent complete heart block occurred in three patients with a membranous ventricular septal defect, in the early postoperative period in two and several years after the successful operation in one. Others (2,7,12,16,18,19) have reported an incidence rate of complete heart block after closure of a ventricular septal defect of 0 to 11%. The presumed mechanism is trauma to the AV node or the bundle of His before its bifurcation (24,25). Complete right bundle branch block occurred in 62% of our patients despite predominantly transatrial closure. The incidence rate in other reports (1,2,16,26–28) has ranged from 33 to 85% with a lower rate reported after transatrial closure. Complete right bundle branch block appears to be tolerated in the short term in infants and children, although the long-term implications of its presence await clarification.

Surgically induced bifascicular block has been suggested as a risk factor for sudden death that occurs after repair of tetralogy of Fallot (29), and more recently after ventricular septal defect closure as well (30). However, none of the patients who acquired bifascicular block in our series died during a follow-up period of 275 patient months. Physical growth and weight gain. Previous authors (16,31) have reported an acceleration of growth after successful cardiac surgery. Similarly, the infants in our series had a rapid gain in weight during the first 18 months after surgery, then assumed a nearly normal growth curve. Most infants who remained below the third percentile in weight despite adequate closure of a ventricular septal defect had a significant associated cardiac or noncardiac abnormality.

Implications. Primary surgical closure of a ventricular septal defect during the first year of life appears to be a relatively safe and effective option for most symptomatic patients. Younger infants with respiratory complications or hemodynamically significant postoperative lesions may experience a higher mortality than older patients or those less severely compromised. After successful ventricular septal defect closure, the majority of infants demonstrate a prompt reduction in pulmonary artery pressure and relief of symptoms. Early intervention also seems to protect against the development of irreversible pulmonary vascular alterations. The incidence of surgically induced complete heart block or complete right bundle branch block is no higher among these infants than that reported after surgery in older patients. Successful operative intervention in the first year of life can be expected to result in near normal growth and development during early childhood.

References


