Left Heart Volume Characteristics Following Ventricular Septal Defect Closure in Infancy

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SUMMARY Left ventricular and left atrial volume, left ventricular ejection fraction, and left ventricular muscle mass were determined preoperatively and postoperatively in 13 patients who underwent surgical closure of ventricular septal defects in the first two years of life. Left ventricular end-diastolic volume and systolic output averaged 255 ± 19% (± SEM) and 240 ± 19% of normal, respectively, before operation but fell to within normal limits postoperatively. Left ventricular ejection fraction was normal preoperatively (100 ± 4% of normal) and remained so after correction (106 ± 3%, NS). Left ventricular mass was mildly elevated at the preoperative catheterization (271 ± 21%) and decreased significantly following repair (P < 0.001). However, the postoperative left atrial volume (147 ± 14%) remained abnormal (P > 0.05). These data suggest that when early surgical closure of a ventricular septal defect is necessary because of failure of medical management, good results with regard to postoperative left ventricular size and function can be expected.

IN A PREVIOUSLY REPORTED STUDY in older children following closure of ventricular septal defects (VSDs), residual abnormalities in left heart size and function were documented. It is possible that prolonged left ventricular (LV) volume overload can produce myocardial changes that at some point in time become irreversible. If so, closure of a VSD earlier in life might be expected to decrease or prevent residual dysfunction. To test this hypothesis, left heart volumes, before and after operative repair, were obtained in children whose clinical management necessitated surgical closure of their VSD before two years of age.

Method

Patient Population

Thirteen patients who underwent surgical closure of VSDs in the first two years of life at Vanderbilt University Hospital were studied with routine diagnostic pre and postoperative cardiac catheterizations. In all patients the VSD was the dominant lesion. One patient had associated mild valvular pulmonic stenosis and a prolapsing aortic leaflet without aortic incompetence, another had a small left or right shunt across a patent foramen ovale, and a third had associated mild peripheral pulmonic stenosis. Eleven of the patients had intracristal VSDs and two had supracristal defects. The patients were submitted for operation in all cases because of congestive heart failure refractory to medical management.

A summary of patient and catheterization data is shown in table 1. The preoperative catheterization was performed at a mean age of 0.7 years (range 0.1–1.7 years). Ages at the time of closure of the VSD range from 0.1 to 1.7 years (mean = 1.1 years). All patients underwent follow-up catheterizations within 2.5 years of repair (mean = 1.5 years) with most being restudied approximately one year postoperatively.

At the preop catheterization all patients had left-to-right shunts exceeding 50% of pulmonary blood flow. The average shunt expressed as a ratio of pulmonary to systemic flow was 3.1:1. Postoperatively, there was only one patient with a residual ventricular level shunt, and this shunt was detected by selective angiography only. A second patient was found to have left ventricular to right atrial communication with a residual shunt of 21% by oximetry.

Right ventricular pressure, preoperatively, averaged 80 ± 5Hg (mean ± SEM) and the mean ratio of right ventricular (RVP) to left ventricular pressure (LVP) was 0.85. The pulmonary to systemic vascular resistance ratio (Rp/Rs) averaged 0.23 preoperatively with a range from 0.08–0.37. Following closure of the defect, RVP fell to a mean of 33 mm Hg and the RVP/LVP to 0.31. Only two patients had residual RV pressures above 40 mm Hg; one of these had peripheral pulmonic stenosis. Because aortic pressure was not recorded postoperatively in most patients, Rp/Rs could not be calculated. Mean pulmonary artery pressure in the postoperative group averaged 15 mm Hg (range 10–20 mm Hg), indicating the lack of significant alterations of pulmonary vascular resistance.

Twelve patients had their defects closed using cardiopulmonary bypass with surface cooling to 28–30°C. One patient, operated upon at 5 weeks of age, was repaired using profound hypothermia (17°C) and total circulatory arrest. All patients had their VSDs closed via a right ventriculotomy. Eight of the thirteen have RBBB following operation; one patient also had intermittent A-V dissociation. All patients are now in sinus rhythm, clinically asymptomatic and require no cardiac medications.

Data Collection

Values for left heart volumes were obtained during catheterization by methods previously described. Catheterizations were carried out using premedication only. Patients less than two years of age received 1 mg/kg each of meperidine and hydroxyzine. Those children older than two years were given Innovar,* 0.025 cc/kg. All premedication was given at least 45 minutes prior to contrast studies. Left heart volume calculations were made from biplane cineangiograms following injection of contrast into

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*Neuroleptic combination of droperidol and Fentanyl
the left atrium, left ventricle, or on the levograde phase of right atrial, right ventricular, or main pulmonary artery injections. Left ventricular and atrial volumes were calculated by the area-length method of Dodge. Left ventricular mass was obtained by the method of Rackley et al. in those patients in whom the free lateral wall of the left ventricle was well visualized. Left ventricular volumes and mass were corrected using regression equations previously reported.

**Results**

The data obtained during the preoperative and postoperative catheterizations are shown in Table 2. The data are expressed in absolute values related to the body surface area and as percent of normal, derived individually by previously published regression equations based on the patient's age, height, and weight.

The findings in regard to left ventricular end-diastolic volume (LVEDV) are shown in Figure 1. As would be expected with a large left to right shunt, the preoperative values for LVEDV are elevated in every patient (255 ± 19%). Following closure of the defect, LVEDV fell to within, or just above, the normal range in all but one patient, whose postoperative LVEDV was mildly elevated at 145% of normal. The postoperative end-diastolic volumes are not significantly different from normal.

**Table 2. Preoperative and Postoperative Catheterization Data**

<table>
<thead>
<tr>
<th>Patient</th>
<th>BSA (cm²/m²)</th>
<th>LVEDV (% normal)</th>
<th>LVEF (% normal)</th>
<th>LVSO (L/min/m²)</th>
<th>LVmass (g/m²)</th>
<th>LAmax (% normal)</th>
<th>cc/m²</th>
<th>% normal</th>
</tr>
</thead>
</table>
| Preoperative
| RB 0.47 97 286 | 0.81 119 11.2 | 283 93 | 111 | 59 | 251 |
| TB 0.35 85 253 | 0.78 114 9.0 | 315 101 | 139 | 63 | 324 |
| KB 0.34 136 437 | 0.63 92 11.4 | 300 | NA | 70 | 311 |
| MC 0.36 107 235 | 0.66 96 10.8 | 261 | NA | 83 | 312 |
| DC 0.49 113 240 | 0.61 90 11.0 | 263 118 | 141 | 76 | 274 |
| AC 0.51 67 197 | 0.57 84 5.0 | 141 | NA | 49 | 218 |
| BF 0.23 57 139 | 0.60 87 5.1 | 136 | NA | 27 | 111 |
| TG 0.46 144 261 | 0.80 117 12.6 | 299 | NA | 79 | 268 |
| DG 0.39 103 326 | 0.65 95 9.1 | 232 140 | 152 | 53 | 229 |
| RH 0.45 162 316 | 0.75 110 13.4 | 321 | NA | 125 | 444 |
| JN 0.17 48 141 | 0.60 88 4.9 | 148 | NA | 63 | 221 |
| JP 0.41 99 200 | 0.58 85 10.8 | 251 | NA | 79 | 309 |

\( X \pm \text{SEM} \)

Postoperative

| RB 0.59 63 101 | 0.81 127 5.6 | 126 | NA | 34 | 130 |
| TB 0.49 66 130 | 0.71 104 5.0 | 116 | 76 | 90 | 39 | 136 |
| KB 0.61 97 145 | 0.67 106 6.3 | 144 | 93 | 112 | 46 | 151 |
| MC 0.66 58 85 | 0.70 111 4.2 | 90 | 79 | 92 | 43 | 135 |
| DC 0.57 66 121 | 0.68 99 5.4 | 117 | 88 | 101 | 36 | 117 |
| AC 0.43 42 95 | 0.68 90 4.3 | 109 | 79 | 93 | 38 | 140 |
| BF 0.60 60 110 | 0.70 111 4.4 | 99 | 59 | 71 | 45 | 167 |
| TG 0.62 75 109 | 0.69 110 7.2 | 136 | 86 | 101 | 45 | 146 |
| DG 0.59 54 87 | 0.75 115 4.7 | 108 | 63 | 76 | 35 | 136 |
| RH 0.62 76 127 | 0.63 100 5.0 | 105 | 85 | 99 | 72 | 299 |
| JN 0.45 48 83 | 0.76 111 5.2 | 129 | NA | 36 | 123 |
| JP 0.50 55 121 | 0.61 97 7.7 | 131 | 94 | 104 | 57 | 133 |
| MQ 0.56 57 138 | 0.54 85 3.7 | 81 | NA | 83 | 30 |

\( X \pm \text{SEM} \)

Abbreviations: BSA = body surface area; LVEDV = left ventricular end-diastolic volume; LVEF = left ventricular ejection fraction; LVSO = left ventricular systolic output; LVmass = left ventricular mass; LAmax = maximal left atrial volume; %N = percent of calculated normal value.
Left ventricular ejection fraction (LVEF), figure 2, was close to or within normal limits in all patients preoperatively (100 ± 4%). Only one patient had a decline in ejection fraction after repair, but her postoperative value remained within normal limits. The postoperative values for LVEF are not significantly different from the preoperative values or from normal.

Results for left ventricular systolic output (LVSO) are shown in figure 3. LVSO was significantly elevated in all but three patients prior to closure. These three patients had shunts expressed as ratios of pulmonary to systemic blood flow of 4.8, 4.0, 5.4 to one. All three of these patients had their preoperative catheterizations performed during early infancy when they were in severe congestive heart failure. The overall value for LVSO preoperatively (240 ± 19%) was significantly increased (P < .01). Following closure of the VSD, however, LVSO fell considerably (116 ± 6%) and is not statistically different from normal.

Left ventricular mass (LV mass) was obtained in only five patients preoperatively (fig. 4). Although LV mass in this small number of patients is statistically increased from normal (P < 0.05), one patient had a normal mass, and the other four values are not as far removed from normal as LVEDV and LVSO are. The ratio of LVEDV/LV mass in these patients averaged 0.81 ± 0.22. Left ventricular mass was within or just below the normal range for all ten patients in whom the postoperative mass was available. All four of the patients for whom both pre and postoperative values were obtained had a decrease in LV mass following closure of the defect.
Results for maximal left atrial volume (LAmx) is grossly elevated in all but one patient, whose value was within normal limits. This is the patient who was found to have an atrial level left to right shunt across a patent foramen ovale. Although LAmx decreased appreciably (271 ± 21% to 147 ± 14%, P < 0.001) following operative repair (fig. 5), the postoperative values remain mildly, but significantly elevated above normal (P < 0.05).

Discussion

Jarmakani and associates have previously reported persistent abnormalities in left ventricular size and pump function in children who had VSDs closed at ages ranging from 3 to 12 years. These authors followed up their original study with an analysis of left ventricular contractile function. In the latter study, they calculated indices of contraction velocity and confirmed the presence of decreased left ventricular contractility in postoperative VSD patients who had had left to right shunts in excess of 40%. None of these patients were less than four years of age at the time of VSD closure.

Maron and co-workers at the NIH subjected 11 patients, who had had VSDs closed three to fifteen years previously, to exercise testing. Five of the patients had abnormally low cardiac outputs in response to exercise stress. Elevations of pulmonary capillary wedge pressures in these patients suggested some degree of left ventricular dysfunction. All five patients were asymptomatic at rest, and all had been repaired after ten years of age. Lucker et al. found a diminished cardiac output in response to exercise in four of 16 postoperative VSD patients. These patients had been repaired at ages three, six, six, and 26 years, respectively, and none had residual shunts. Five other patients, some of whom did have residual shunts, had borderline normal cardiac output response to exercise.

The results of this investigation indicate that LVEDV, LVSO, and LV mass return to normal in patients whose VSDs were closed in the first two years of life. Further, there is no fall in left ventricular pump function as measured by the ejection fraction. Only left atrial volume remained elevated above normal in this group of patients. We are uncertain as to why LA volume remains above normal in these patients. Perhaps permanent changes in elasticity of this chamber occur preoperatively with the marked degree of dilatation which is usually present. Overstretching of the relatively thin-walled atrial chamber could produce such an effect which could prevent a return to a normal volume following relief of the volume load. Under these conditions, the infant or child must “grow into” their enlarged left atrium as sometimes is the case with a markedly enlarged ventricle. In this study five of 13 patients showed a decrease in LVEDV in both absolute (ml) as well as relative size while six of 12 patients showed an absolute as well as relative decrease in LAmx. Whether or not an actual decrease in chamber size is recorded from one study to the next obviously depends to a great extent on the time between studies and the child’s change in size in the interim.

None of our patients has been subjected to exercise stress nor are pressure-velocity indices available. However, ejection fraction is a useful parameter for measuring cardiac performance, if preload and afterload are constant. Both increased preload and decreased afterload tend to elevate the ejection fraction. The presence of both increased preload, (i.e. LVEDV), and decreased afterload, via ejection across the VSD into the pulmonary circuit, likely contribute to the normal preoperative values for ejection fraction in our patients. Following closure of the defect, both preload and afterload tend to normalize and any intrinsic depression of left ventricular function should become manifest as an abnormally low ejection fraction. The persistence of normal ejection fractions in all our patients following repair of the VSD is an encouraging finding.

The obvious difference in our patients and those previously reported is age. Several authors have pointed out decreased contractility in hypertrophied cardiac muscle. The anatomic correlate of this phenomenon may well be the diffuse cardiac sclerosis reported by Krymsky in various forms of congenital heart disease, including VSD. Dr. Krymsky reported finding areas of sclerosis in young people, even infants, but states “The older a patient is, i.e., the longer the duration of disease, the larger was the degree of cardiac sclerosis.” It could be suggested, therefore, that the better functional status of the infants reported in this study is related to the shorter length of time that their hearts were subjected to abnormal work requirements.

Other differences should be considered, however. Perhaps the major one is operating room procedure. The patients who made up Jarmakani’s study had their VSDs closed in the early and middle 1960s. Operative technique has changed considerably over the past decade with far greater appreciation being given to the possible permanent effects of myocardial ischemia produced during intra-cardiac manipulation. Our patients, with one exception, had their defects closed using cardiopulmonary bypass and surface cooling with intermittent cross-clamping of the aorta. It is conceivable, though not established, that the intraoperative
procedures used in our patients served to protect their hearts
to a greater degree than was possible ten years ago, and
that this factor contributed to the better functional result.

Another factor that should be considered is the relative
lack of hypertrophy as compared to dilatation demonstrated
by the five patients for whom we have preoperative mass
data. These patients showed relatively little hypertrophy for
the degree of volume overload to which their left ventricles
were subjected. The LVEDV/LV mass ratio of 0.81 in our
patients compares to a LVEDV/LV mass of 0.69 (± 0.13) in
14 patients less than two years of age with VSDs not requir-
ing early closure.12 The same ratio was 0.49 ± 0.09 in ten
normal children of the same age.12 This relative lack of
hypertrophy may, in fact, be the underlying reason for
failure of medical management in these patients. On the
other hand, the same lack of severe hypertrophy may have
spared these patients the relative myocardial ischemia that
may accompany the hypertrophic process, and thus have left
them with better myocardial function once the volume
overload was relieved.

Although the underlying mechanism is not clear, these
data indicate that closure of VSDs in infancy can be ex-
pected to produce a good result in regard to left ventricular
size and function, at least in the short term. Many factors
must be weighed before early surgical closure of a VSD is
undertaken. Our patients were operated upon because of
refractory congestive heart failure and not for reasons of
prophylaxis in preserving cardiac function. However, when
early operative intervention is required, it is encouraging
that good myocardial functional results can be expected.

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The Normal Spectrum of Mitral and Aortic Valve Discontinuity

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SUMMARY The relationship of the base of the left and non-
corony sinususes of the aortic valve and the adjacent aortic leaflet of
the mitral valve was studied in 106 normal heart specimens and 184
specimens with isolated VSD. The results show a spectrum of per-
sistence of the tissue along the inner curvature of the heart. This may
help settle the recent controversy in the interpretation of echocardi-
ograms of this area because the recorded mitral-aortic discontinuity
may be due to this spectrum rather than to variations in technique.

that they are separated by only a thin band of fibrous tissue.
A wider separation of these valves (discontinuity) has been
of recent interest in the diagnosis of malposition of the great
arteries1-3 including double outlet right ventricle4-4 because
the mitral and adjacent semilunar valves are usually
separated by a band of muscle, believed to be either per-
sistence of the aortic conus2,* or bulboventricular flange.

In this paper we describe a variable relationship of the
base of the left and noncorony sinususes of the aortic valve
to the adjacent anterior leaflet of the mitral valve in normal
hearts and in specimens with isolated VSD, and suggest that
this variable relationship is probably pertinent to recent
echocardiographic evaluations of this region.7-10

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WITH CONTINUITY of the aortic and mitral valves, the
anterior leaflet of the mitral and adjacent sinususes of the
aortic valve are in such close proximity at the base of the heart

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