Ventricular Septal Defect in Infants and Children
A Correlation of Clinical, Physiologic, and Autopsy Data

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Now that ventricular septal defect is amenable to surgical repair it is most important
to define the indications for surgical intervention. In this paper the natural history
of the disease and its clinical and physiologic characteristics are carefully detailed.
These observations permit better recognition and understanding of the condition and
offer a basis for comparison with results after surgery.

IT HAS BEEN demonstrated recently that
ventricular septal defects in children can
be repaired surgically with an acceptable morta-
tility rate under appropriate circumstances.1-3
For infants who at present are not considered
suitable candidates for direct surgical repair,
an ingenious palliative operation offers con-
siderable theoretical promise.4 To achieve a
better understanding of the nature of the anom-
aly and to arrive at some working hypo-
thesis in regard to operative indications, we
reviewed the clinical picture, the physiologic
data, and the natural history of our patients
with proven ventricular septal defect.

MATERIALS AND METHODS

The physiologic data were surveyed on all
patients admitted to the Children's Medical
Center, Boston, between 1950 and 1956 and diagnosed
at cardiac catheterization as having a ventricular
septal defect. All these subjects had an increase in oxygen content of at least a 1.0 volume per
cent at the right ventricular level as compared
to the right atrial sample. The catheterized pa-
tients were considered to have severe disease on
clinical grounds; thus they represent a select
group from the total number of children with ven-
tricular septal defect attending our clinic.

The catheterization data were reviewed for
completeness and all patients with associated car-
diac anomalies other than pulmonary stenosis or
aortic regurgitation were arbitrarily excluded.
Cases of ventricular septal defect and pulmonary
stenosis with a resting arterial saturation of less
than 94 per cent were also eliminated as examples

of the tetralogy of Fallot.6 The remaining 98
patients form the basis of the present report.

All patients were studied with 7-foot radiograms
and fluoroscopy. All had at least one 12-lead
electrocardiogram that was classified in regard to
ventricular hypertrophy. Phonocardiographic ob-
servations were made on about one quarter of the
patients by means of a Sanborn Stetho-Cardiette
or Twin-Beam apparatus.

Cardiac catheterization was carried out under
sedation either with opiates or a combination
of Demerol, Phenergan, and Thorazine. The cathe-
ters used were Courmand or Lehman no. 5 or no.
6. Pressure measurements were obtained with
Sanborn electromanometers or Statham P-23-D
strain-gage manometers. A Sanborn Polyviso re-
cording apparatus was used. Blood oxygen deter-
minations were made by the Van Slyke or
spectrophotometric technics.8 Oxygen consump-
tion was determined, when possible, by collection
of expired air samples in a Douglas bag and analysis
by means of a Tissot spirometer and a Pauling
oxygen analyzer; in the others it was estimated
on the basis of 180 ml./min./M2. Zero level for
pressure was assumed to be at one half the
anteroposterior diameter of the chest. Pulmonary
venous oxygen saturation was assumed in all
instances to be 98 per cent of capacity. (We are
fully aware that the calculation of shunts derived
on the basis of this figure may be of questionable
accuracy in some instances, particularly in infants.)

In order to simplify the evaluation of the case
material, certain arbitrary definitions were made.
Pulmonary stenosis was considered to be present
when a systolic gradient of at least 25 mm. Hg
existed between right ventricle and pulmonary
artery. Pulmonary vascular resistance was cal-

*One small infant with ventricular defect and
pulmonary stenosis, a large left-to-right shunt, and
resting arterial saturation of 93 per cent was not
excluded, since slight pulmonary venous unsaturation
at cardiac catheterization is not uncommon in small
infants.
TABLE 1.—Physiologic Classification of 98 Patients with Ventricular Septal Defect

<table>
<thead>
<tr>
<th>Uncomplicated</th>
<th>Complicated</th>
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<tr>
<td>Left-to-right shunt</td>
<td>Left-to-right shunt</td>
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<tr>
<td>Small 18</td>
<td>Pulmonary stenosis 20</td>
</tr>
<tr>
<td>Large 24</td>
<td>Pulmonary vascular obstruction 36*</td>
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</table>

*Includes 2 patients with pulmonary stenosis and pulmonary vascular obstruction.

In addition to the 98 patients with complete clinical and physiologic studies, we also included in this report 5 patients with uncomplicated ventricular septal defect in whom complete autopsy data are available. These children will only be discussed in terms of course and prognosis since the clinical data available on them are incomplete.

**Observations**

**History**

*Discovery of Heart Disease.* In the majority, heart disease was diagnosed on the basis of the discovery of a murmur in infancy. Fifty-seven children had a murmur noted at the age of 3 months or earlier, but only 13 of these were reported to have been present "at birth." Twelve patients were first noted to have a murmur after the age of 1 year. The time of discovery of heart disease was independent of the size of left-to-right shunt, the presence or absence of pulmonary stenosis or pulmonary vascular obstruction.

Of 85 cases with sufficient information, 45 were found to have heart disease on routine or chance examination, whereas 40 were seen by a physician because of symptoms referable to heart disease.

*Symptoms.* By and large, symptomatology was most marked in early infancy; of the 52 patients with severe symptoms, 43 were less than 1 year of age. The correlation of symptomatology with the basic physiologic information is presented in figure 1. Poor growth was reported by the parents in about two thirds of this series. Contrariwise, specifically recorded "good" growth was unusual and of the 19 instances in which it occurred, 7 were patients with pulmonary stenosis.

One or more episodes of congestive failure appeared in the history of 34 patients; in many small infants this diagnosis was confused by the presence of pneumonia.

A vague history of intermittent, mild cyanosis with respiratory difficulty or with crying, disappearing after the first few weeks of life, was obtained in 34 patients. Indeed, 4 patients were initially examined in the neonatal period because of cyanosis. This symptom was surprisingly common among the children with uncomplicated small left-to-right shunts.
Ten patients gave a history of late appearance of mild cyanosis on exercise; 9 of these had either associated pulmonary stenosis or elevated pulmonary vascular resistance.

The following other problems appeared in the histories of some patients: squatting 7 (uncomplicated left-to-right shunt 3, pulmonary vascular obstruction 3, pulmonary stenosis 1); paroxysmal tachycardia 5; subacute bacterial endocarditis 3 (aortic regurgitation 2); hemoptysis 2; acute rheumatic fever 1; chest pain 1; and mongolism 1.

**Physical Examination**

The salient features of the physical examination as recorded during the admission for cardiac catheterization are presented in figure 2, and the associated anomalies are listed in table 2. Of 98 patients more than one third were markedly underweight, falling below the third percentile on our standard growth charts; 70 were below the twenty-fifth percentile. Height measurements were proportional to weight measurements. The poorest growth was noted in patients with elevated...
pulmonary vascular resistance; only 3 patients in this group were above the twenty-fifth percentile for weight.

Cyanosis was suspected clinically in 17 patients, 11 of whom had in fact arterial oxygen saturation below 94 per cent at catheterization (table 3). An additional 13 patients had clinically unsuspected arterial unsaturation.

The chest was considered asymmetrical or deformed in anteroposterior diameter in 80 patients. The presence of a large shunt was almost invariably associated with prominence of the left chest; patients who had no chest deformity tended to have small hearts by x-ray.

All infants under the age of 2 years showed a right ventricular impulse alone, or in combination with a left ventricular impulse. A purely apical impulse was often associated with electrocardiographic evidence of left ventricular hypertrophy or with a normal electrocardiogram. The correlation of right ventricular hypertrophy with a xiphoid impulse was not striking. Almost all patients with a pure xiphoid impulse, however, had a right ventricular systolic pressure of over 45 mm. Hg.

A thrill was noted in 72 patients. It was usually present in the group of uncomplicated left-to-right shunts and in those who had associated pulmonary stenosis. By contrast, less than one half of the patients with increased pulmonary resistance showed a thrill.

The first heart sound was not uniformly commented upon, but we have the distinct impression that it was masked by the loud systolic murmur at the lower left sternal border in a high percentage of cases.

A third heart sound was heard in 51 patients and was associated with a low-frequency diastolic murmur at the apex or lower left sternal border in all but 2 instances.

The second heart sound at the second left intercostal space was analyzed most carefully, both in regard to splitting and intensity. A split second sound was found in all but 12 individuals; one half of these had pulmonary vascular obstruction. The second heart sound was obscured in 4 of the 5 patients with aortic regurgitation.

The intensity of the second sound at the pulmonary area correlated fairly well with the mean pulmonary artery pressure (table 4). Decreased intensity of the second heart sound was associated with a mean pulmonary artery pressure of less than 30 mm. Hg in all but 1 infant. Increased intensity of the second heart sound was not quite so specific, still almost 80 per cent of the patients with increased second sound at the second left interspace had a mean pulmonary pressure over 30 mm. Hg.

Systolic Murmur. A blowing, holosystolic murmur was present in every case of this se-
VENTRICULAR SEPTAL DEFECT IN CHILDREN

![Phonocardiogram](image)

**Fig. 3** Top. Phonocardiogram taken at the lower left sternal border in patient with ventricular defect. Note the high intensity, medium frequency, holosystolic murmur (SM). 1, first sound; 2, second sound; 3, third sound.

**Fig. 4** Middle. Phonocardiogram at apex of patient with ventricular defect. Note the lower intensity systolic murmur and the low-frequency middiastolic murmur (DM).

**Fig. 5** Bottom. Phonocardiogram at mid-left sternal border of patient with ventricular defect, aortic regurgitation, and mild pulmonary stenosis. Note the high-frequency and intensity diamond-shaped systolic murmur (SM) and crescendo-decrescendo diastolic murmur (DM).

ries (fig. 3); in 82 the murmur was maximal at the mid- or lower left sternal border. Of the 8 patients recorded as having a systolic murmur maximal at the upper sternal border, 5 had associated pulmonary stenosis. Of the 8 patients with an apical murmur, 7 had pulmonary vascular obstruction. As may be seen from table 5, murmurs of lesser intensity were rather common in the group with pulmonary vascular obstruction, but relatively rare in all the other subdivisions.

**Diastolic Rumbling Murmurs.** A low frequency, low to moderate intensity, middiastolic or presystolic murmur maximal at the apex or lower left sternal border was present in 72 patients (fig. 4). These murmurs usually began with the third sound and were quite short in duration. Whether they appeared in middiastole or presystole seemed to depend principally on the heart rate.

As seen in figure 2, a large proportion of all 4 physiologic groups had low-frequency diastolic murmurs, but the pure, large left-to-right shunts had this murmur almost without exception.

In table 6 the heart size and the size of the shunt are related to the presence or absence of a diastolic rumbling murmur. If a patient with a ventricular septal defect had an apical diastolic rumble, it was very likely that he would have appreciable cardiac enlargement,
but not necessarily a large shunt. Conversely, absence of a diastolic rumble meant that the patient probably had only a small left-to-right shunt, but may or may not have had significant cardiac enlargement.

**Diastolic Blowing Murmurs.** A protodiastolic, high-frequency, blowing murmur of high intensity was heard along the left sternal border in 24 patients (fig. 5). These murmurs were associated with an elevated mean pulmonary artery pressure (over 40 mm. Hg) in all but 9 patients; 4 of the latter group had clear-cut aortic regurgitation.

**Electrocardiogram**

Of the total of 267 electrocardiograms available, those taken during admission for cardiac catheterization were used for detailed analysis (fig. 6). The others were evaluated only for changes through the years.

**Axis Deviation.** Left axis deviation (0 to -30°) was uncommon, appearing only 9 times in the entire group. Two of these children had otherwise normal tracings, 1 (a child with pulmonary stenosis) had pure right ventricular hypertrophy, and in the others left ventricular hypertrophy alone or in combination with right ventricular hypertrophy was present.

By contrast, right axis deviation (+90 to +180°) was common, appearing 31 times in the entire series. In 29 tracings there was right ventricular hypertrophy alone or in combination with left ventricular hypertrophy. One patient with a large uncomplicated left-to-right shunt showed right axis deviation and pure left ventricular hypertrophy; another showed no evidence of ventricular hypertrophy.

Normal axis deviation (0 to +90°) was present in well over one half the total series and bore no specific relationship to the various ventricular hypertrophy patterns. Indeterminate axis was uncommon and likewise bore no relationship to the patterns of ventricular hypertrophy.

**Incomplete Right Bundle-Branch Block.** An rSr' or rsR' pattern in the right chest leads with a ventricular activation time of at least 0.04 second was found in 54 cases. No definite relationship could be established between this finding and evidence of right, left, and combined ventricular hypertrophy.

**P Pulmonale.** A P wave of at least 2.5 mm. in height with a "peaked" contour in the right precordial leads or in lead II was found in 17 patients. Fourteen of these had either associated pulmonary vascular obstruction or pulmonary stenosis. Six had arterial oxygen saturations of less than 94 per cent, all with pulmonary vascular obstruction. There was no correlation between the right atrial mean pressure and the presence of P pulmonale.

**P Mitrale.** Notched or flat-topped P waves in the standard leads I and II or in the left precordial leads were found in 11 patients. In all but 1 there was left ventricular dominance or hypertrophy alone or in combination with right ventricular hypertrophy. Satisfactory mean pulmonary wedge pressures, obtained in 5 of these 11 patients, ranged from 11 to 17 mm. Hg. There was no correlation between the presence of P mitrale and the right atrial mean pressure.

**Combined Atrial Hypertrophy.** An abnormally broad and tall P wave in any of the standard or precordial leads was found in 6 patients. Five of these had pulmonary vascular obstruction.

**Prolonged P-R Interval.** An abnormally long P-R interval for heart rate and age, according to our tables of normal subjects, was seen only 11 times in the entire series and was not associated with any particular physiologic subgroup.

**S-T and T-Wave Changes.** Significant de-
VENTRICULAR SEPTAL DEFECT IN CHILDREN

pression of the S-T segment and inversion of the T wave in the left precordial leads ("strain-pattern") was observed in 7 cases. Five of these had aortic regurgitation and 2 had uncomplicated large left-to-right shunts.

Because of the difficulties in interpreting degrees of right precordial T-wave inversion in infants and small children, no attempt was made to determine the incidence of "right strain pattern."

**Ventricular Hypertrophy.** Pure right ventricular hypertrophy was seen in 32 patients, almost all individuals with pulmonary stenosis or vascular obstruction. Of the 3 patients with pure right ventricular hypertrophy who had large uncomplicated left-to-right shunts, one had a functionally single ventricle, another was still an infant when last observed, and the third had borderline infundibular pulmonary stenosis (gradient 23 mm. Hg). No patient with an uncomplicated small shunt had pure right ventricular hypertrophy.

Pure left ventricular hypertrophy was present in 32 children; most of these fell into the uncomplicated left-to-right shunt group but a few had associated pulmonary stenosis. Surprisingly enough, 2 patients with pure left ventricular hypertrophy had pulmonary vascular obstruction; one was still an infant when last observed and the other had only minimal elevation of pulmonary vascular resistance (4.0 units).

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**Fig. 6 Left.** Electrocardiogram related to physiologic classification. IRBB, incomplete right bundle-branch block; RVH, right ventricular hypertrophy; LVH, left ventricular hypertrophy.

**Fig. 7 Right.** X-rays related to physiologic classification. PA, pulmonary artery; LA, left atrium; PV, pulmonary vasculature.

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Combined ventricular hypertrophy was seen in 20 patients, most of them with pulmonary vascular obstruction.

There were 14 patients who showed no evidence of ventricular hypertrophy. These electrocardiograms were found only in the uncomplicated left-to-right shunt groups.

X-Ray

The x-ray and fluoroscopic studies performed during admission for cardiac catheterization were analyzed in detail (fig. 7); the other available films were used to determine changes over the years and will be discussed in the section on course and prognosis.

Heart Size. It may be seen that most patients had moderate or marked cardiac enlargement; as pointed out earlier, this was a group selected for cardiac catheterization on account of severe disease. It is interesting that patients with small uncomplicated left-to-right shunts may on occasion have significant cardiac enlargement. Contrariwise, individuals with pulmonary vascular obstruction and large left-to-right shunts may have only relatively small hearts under exceptional circumstances. When the heart size was correlated with a prior history of congestive heart failure or pneumonia, it appeared that patients with such a past history were more likely to have definite cardiac enlargement. However, the presence of cardiomegaly could not be taken as evidence for pre-existing congestive failure or pneumonia (table 7).

Cardiac Contour. It may be seen from figure 7 that the radiologic interpretation of ventricular enlargement was not particularly helpful in attempting to distinguish the physiologic groups. A normal contour was discernible in 2 patients with marked vascular obstruction, and pure right ventricular enlargement was thought to be present in 8 individuals with small shunts. Figures 8 and 9 show the extreme difference noted in patients with marked pulmonary vascular obstruction.

![Fig. 8 Left. Relatively normal cardiac contour in patient with pulmonary vascular obstruction.](image)

![Fig. 9 Right. Grossly abnormal cardiac silhouette in another patient with pulmonary vascular obstruction.](image)
No close correlation between electrocardiographic ventricular hypertrophy and ventricular enlargement as determined by x-ray could be found; nor was it possible to establish a relationship between the right ventricular systolic pressure and the ventricular contour at x-ray.

**Main Pulmonary Artery Segment.** A significantly enlarged main pulmonary artery segment seemed to indicate that the patient had either pulmonary vascular obstruction or a large left-to-right shunt, but only 3 of the patients with pulmonary stenosis showed enlargement of the main pulmonary artery segment. The pulmonary artery segment was large in one half of the patients with pulmonary artery mean pressure above 40 mm Hg and was of normal size in the majority of patients with mean pressures below this figure.

**Left Atrial Enlargement.** Left atrial enlargement was present in three fourths of the children with large uncomplicated left-to-right shunts or pulmonary vascular obstruction, but it was not unusual in the other groups either. There was no clear-cut correlation between the size of the left atrium and the size of the left-to-right shunt.

**Pulmonary Vasculature.** The average diameter of the pulmonary vessels in the middle third of the lung fields was considered to be greater than normal in 77 individuals. Every patient with a large, uncomplicated left-to-right shunt had this finding but it was present also in about one half of the cases with small, uncomplicated shunts. Three quarters of our group with associated pulmonary stenosis and 90 per cent of the children with pulmonary vascular obstruction also had engorged pulmonary vessels.

In 4 patients, all with pulmonary vascular obstruction, there was pulmonary vascular engorgement in the middle third of the lung fields with relative ischemia in the periphery.

Two children with pulmonary vascular obstruction showed asymmetrical pulmonary vasculature and in both instances the vessels were decreased in prominence on the left and increased (with unilateral "hilar dance") on the right.

**Expansile Pulsations.** Expansile pulsations were noted in over 50 per cent of the patients in this series and, though it was not seen in every child with pulmonary vascular engorgement, the incidence of "hilar dance" was proportional to the evidence of engorged pulmonary vessels.

**Right Aortic Arch.** A right aortic arch was present in 5 patients. Four of these had associated pulmonary stenosis, but 1 patient with a small uncomplicated left-to-right shunt also had a right aortic arch.

**Catheterization Data**

Table 8 presents a general survey of the physiologic data. Included in the total are, for instance, all patients with small shunts
TABLE 9.—A-H. Detailed Physiologic Data

<table>
<thead>
<tr>
<th>Blood oxygen and pressure measurements</th>
<th>Small left-to-right shunt</th>
<th>Large left-to-right shunt</th>
<th>Pulmonary stenosis</th>
<th>Pulmonary obstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arteriovenous oxygen difference (vol. %)</td>
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<td>Pulmonary (PV*-PA)</td>
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<td>12</td>
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<td>Mean pulmonary artery pressure</td>
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<td>Pulmonary artery pressure</td>
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<td>Average pulse pressure</td>
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<td>Brachial artery pressure</td>
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<td>Average systolic pressure</td>
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<td>103</td>
<td>109</td>
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<td>Average pulse pressure</td>
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<tr>
<td>No. of cases†</td>
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**TABLE 9.—(Continued)**

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<thead>
<tr>
<th>Blood oxygen and pressure measurements</th>
<th>Small left-to-right shunt</th>
<th>Large left-to-right shunt</th>
<th>Pulmonary stenosis</th>
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<td>Per cent brachial artery saturation</td>
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<td>18</td>
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</tbody>
</table>

*Assumed to be 98% capacity.
†Five patients with aortic regurgitation not included.
‡Infant under age 6 months.
BA, brachial artery; PA, pulmonary artery; PV, pulmonary vein; RA, right atrium; RV, right ventricle.

including those with pulmonary stenosis and vascular obstruction as well.

For the purposes of this study, a left-to-right shunt producing a pulmonary flow twice the size of the systemic flow was taken as the dividing line between a large and a small shunt. There were 10 patients with calculated shunts of very large size; subject to previously noted errors, these shunts produced a pulmonary flow 4 to 5 times the systemic flow (pulmonary atroventricular difference of less than 1.0 volume per cent) (table 9).

Pulmonary stenosis, in this series, was arbitrarily defined as a systolic pressure gradient between right ventricle and pulmonary artery of 25 mm. Hg or more. A right ventricular-pulmonary artery gradient occurred in association with small and large left-to-right shunts but no correlation could be found between the size of the shunt and the severity of the gradient. The interesting combination of pulmonary stenosis with increased pulmonary vascular resistance was observed twice. On the basis of continuous pressure tracing obtained during withdrawal of the
TABLE 10.—Total Autopsy Material on Ventricular Defect from the Pathology Department, Children's Medical Center, 1950-1956

<table>
<thead>
<tr>
<th>Case</th>
<th>Age (yr.)</th>
<th>Size ventricular septal defect (cm.)</th>
<th>Diameter of aortic valve (cm.)</th>
<th>Associated anomalies</th>
<th>Cause of death</th>
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<td>1</td>
<td>2/12</td>
<td>0.4 x 0.2</td>
<td>0.7</td>
<td>Marked pulmonary vascular changes</td>
<td>Pneumonia</td>
</tr>
<tr>
<td>2</td>
<td>1/12</td>
<td>0.4 x 0.2</td>
<td>0.7</td>
<td>Bicuspid pulmonary valve, aortic incompetence, patent ductus arteriosus (0.7 cm. diameter)</td>
<td>Pneumonia</td>
</tr>
<tr>
<td>3</td>
<td>8/12</td>
<td>1.0</td>
<td>0.95</td>
<td>Mongolism, patent ductus arteriosus (0.2 cm. diameter)</td>
<td>Pneumonia, congestive heart failure</td>
</tr>
<tr>
<td>4</td>
<td>3/12</td>
<td>0.8 x 0.8</td>
<td>0.8</td>
<td>Mitral and tricuspid incompetence with fibroelastosis of these valves</td>
<td>Congestive heart failure, mycotic pneumonia</td>
</tr>
<tr>
<td>5</td>
<td>5/12</td>
<td>0.2 x 0.1</td>
<td>0.9</td>
<td>None</td>
<td>Pneumonia</td>
</tr>
<tr>
<td>6</td>
<td>23/12</td>
<td>0.8</td>
<td>1.4</td>
<td>Marked pulmonary vascular changes</td>
<td>Cardiac catheterization</td>
</tr>
<tr>
<td>7</td>
<td>13</td>
<td>2.0</td>
<td>2.5</td>
<td>Aortic regurgitation</td>
<td>Congestive heart failure, exploratory thoracotomy</td>
</tr>
<tr>
<td>8*</td>
<td>5</td>
<td>2.2 x 1.8</td>
<td>1.4</td>
<td>Bicuspid aortic valve muscular defect</td>
<td>Pneumonia, congestive heart failure</td>
</tr>
</tbody>
</table>

*Autopsy at the Massachusetts General Hospital, Boston.

catheter from the pulmonary artery, 6 patients were thought to have pure infundibular stenosis, 5 pure valvular stenosis, and 6 combined stenosis. There was definite correlation between the appearance of the pulmonary artery segment at x-ray, the site of maximal intensity of the murmur, and the site of stenosis as judged by cardiac catheterization.

Of the 36 patients with pulmonary vascular obstruction one third had a resistance over 9.0 units (720 dyne-sec.-cm.⁻²) and one third had a resistance between 3.0 to 6.0 units. The error in these calculations is, of course, proportional to the error in calculating shunt size and estimating pulmonary wedge pressure.

Course of the Catheter. The right atrium, right ventricle, and pulmonary artery were entered in every case. The catheter was passed directly into the aorta in 6 children, into the left atrium via the atrial septum 4 times, and directly into the left ventricle via a ventricular septal defect 5 times.

Oxygen Consumption. Oxygen consumption was measured directly in 50 patients with an average oxygen consumption of 189 ml./min./M.²

Blood Oxygen and Pressure Measurements. Table 9 presents the detailed physiologic observations. As expected, the individuals with uncomplicated large left-to-right shunts and those with pulmonary stenosis, most of whom

TABLE 11.—Progression of Symptoms in 35 Cases (3 Dead)

<table>
<thead>
<tr>
<th>Severe symptoms</th>
<th>Mild symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small</td>
</tr>
<tr>
<td>----------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Infancy</td>
<td>3</td>
</tr>
<tr>
<td>Same</td>
<td>1</td>
</tr>
<tr>
<td>Better</td>
<td>2</td>
</tr>
<tr>
<td>Status last seen</td>
<td>1</td>
</tr>
</tbody>
</table>

*Pulmonary stenosis.
†Pulmonary vascular obstruction.
also had large left-to-right shunts, had the smallest atrioventricular differences. The right atrial mean pressures with few exceptions were under 10 mm. Hg. The mean "pulmonary capillary wedge" pressures, reflecting left atrial pressure, were in 15 mm. Hg in 9 of 58 patients. Thirty-three of the patients with pulmonary vascular obstruction and 6 of the patients with pulmonary stenosis had a mean pulmonary artery pressure over 40 mm. Hg. The average systolic, diastolic, and pulse pressures of the pulmonary and systemic arteries are presented in table 9. The systemic arterial systolic pressure and the right ventricular systolic pressure were virtually identical (difference less than 20 mm. Hg) in 37 patients, the majority having pulmonary vascular obstruction. Table 9 also presents a survey of the systemic arterial oxygen saturation. It may be seen that there were 24 children with arterial saturation less than 94 per cent, but only 5 below 90 per cent. As mentioned before (table 3) 11 of these children with arterial unsaturation were recognized clinically to be cyanotic; 6 of the unrecognized ones were infants.

Course and Prognosis

Fifty-two patients were followed for 1 year or longer with an average follow-up of 5 years; 49 of these are alive at present. One of the 3 died after cardiac catheterization, the second one with equivocal catheterization findings during exploratory thoracotomy to exclude a patent ductus arteriosus, and a third at another hospital in congestive failure. Of the 48 patients first seen in infancy, 38 have been subsequently examined and all of these with the exception of the one lost at cardiac catheterization are living.

Our pathology department was consulted to determine the number of patients with uncomplicated ventricular septal defect autopsied in this hospital in the six years covered by this report. Five additional patients with ventricular septal defect who were autopsied but not included in the clinical data were found. Patients with ventricular septal defect who had additional cardiac defects, outside the scope of this paper, were excluded. The pertinent autopsy data in the 8 patients representing our total autopsy material on ventricular septal defects are presented in table 10. The size of these defects was related to the aortic valve size as suggested by Selzer.10

Two of these infants died within hours after admission to the hospital, not having been recognized as patients with congenital heart disease previously. Probably the patent ductus arteriosus and the aortic valve abnormality contributed to the demise of case 2. Whether functional tricuspid or mitral incompetence was present in case 4 can hardly be accurately determined at autopsy; however, the valves were opaque and obviously abnormal. It is difficult to imagine how the minute ventricular defect in case 5 could have been responsible for the death of the patient.

It is worth noting that all but the 2 children lost during operative procedures had severe pneumonia, a frequent cause of death in infancy by itself.

Progression of Symptoms. The progression of symptoms over the years, as estimated by personal observation and the narrative of the

| Table 12.—Changing Growth Pattern of 32 Children with Ventricular Defect (Weight)* |
|----------------------------------|----------|----------|----------|
| Under 3% | 3 to 10% | 10% | over 10% | Total |
| Under age 1 year | 18 | 10 | 4 | 32 |
| Improved | 4 | 5 | 0 | 9 |
| Deteriorated | 1 | 1 | | |
| Over age 2 years | 15 | 4 | 13 | 32 |

*First examined under age 1 year and followed for 2 years or longer.

Based on Stuart, H. C., anthropometric chart, The Children's Medical Center, Boston, Mass.

**Table 13.—Progression of Electrocardiographic Pattern of 52 Children with Ventricular Defect**

<table>
<thead>
<tr>
<th>Followed for one year or longer*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial ECG</td>
</tr>
<tr>
<td>Changed</td>
</tr>
<tr>
<td>24</td>
</tr>
</tbody>
</table>

*Average follow-up 5 years.
Individuals there were no significant changes in the intensity of the systolic murmur. Determination of the presence or absence of a low-frequency diastolic murmur is difficult in infancy; thus the time of discovery may not coincide with its appearance. Contrariwise, it seemed significant to us that in at least 3 children, well-documented apical diastolic murmurs disappeared as they grew older and their general condition improved.

**Progression of Electrocardiographic Findings.** Fifty-two patients had multiple electrocardiograms taken over a period of 1 or more years. Of these, 24 were under 1 year of age when the first electrocardiogram was taken. Eighteen of these 24 have shown no significant changes despite observations as long as 6 to 7 years in some cases. Of the 28 patients whose first electrocardiogram was taken after the age of 1 year, there were 7 who developed a subsequent change in pattern (table 13).

Table 14 presents a detailed analysis of the changes in the electrocardiograms in 13 children.

Only 2 of the entire group of 13 patients with a changing electrocardiographic pattern developed signs of right ventricular hypertrophy. One, at age 2 years, developed abnormal right ventricular hypertrophy having previously had a normal electrocardiogram, and the second switched from left ventricular hypertrophy at age of 8 years to right ventricular hypertrophy at age 11 years while developing the clinical picture of the tetralogy of Fallot (fig. 10). Six—all with uncomplicated large left-to-right shunts—of the 13 developed pure left ventricular hypertrophy, and 5, all proved to have pulmonary vascular obstruction, developed combined ventricular hypertrophy.

The patients with large uncomplicated left-to-right shunts were the most likely to have shown a changing electrocardiographic pattern; 8 of 13 showed this change. Four patients had pulmonary vascular obstruction and 1 had associated pulmonary stenosis.

**Progression of X-ray Findings.** There were 42 patients with x-ray examinations extend-
of these investigations will be reported in a separate communication.

Conclusions

It is our impression that the 4 hemodynamic variants of ventricular septal defect (uncomplicated large or small left-to-right shunts, associated pulmonary stenosis or pulmonary vascular obstruction) represent a wide spectrum of physiologic situations. Our data suggest that the clinical findings also show a similar pattern.

The size of the shunt may change with the growth of the patient. Although we do not have enough repeated cardiac catheterizations on individual patients to prove this point, the findings relative to the natural history of the disease suggest this possibility. There are individuals in the uncomplicated small left-to-right shunt group who, prior to catheterization, had distinct improvement in heart size, pulmonary vascular engorgement, growth, and symptoms. Contrariwise, there was evidence in some of our patients, particularly in the uncomplicated large left-to-right shunts, of deterioration through the years prior to catheterization as shown by late appearance of severe symptoms, electrocardiographic abnormalities and congestive heart failure. Although these changes in either direction may depend on causes other than variation in the size of the shunt (i.e., myocardial factors), the possibility that this is the underlying reason has to be considered. This changing clinical picture demonstrates the difficulties of rigid classification according to shunt size.

Similar phenomena are observed in children with ventricular septal defect and associated pulmonary stenosis. There are patients with evidence of a large left-to-right shunt and minimal pulmonary stenosis in infancy who develop through the years into "cyanotic" instances of tetralogy of Fallot, showing definite arterial unsaturation on exercise.11

Interestingly enough, the group with pulmonary vascular obstruction has been the most stable in our entire series. In contrast to the opinions of others,12, 13 we have failed
to find significant progression in the clinical picture of any of our patients with pulmonary vascular obstruction. Although we do not doubt that deterioration does occur later in life, we have no evidence that it has happened to any of the children studied by us.

Not only do some of the patients with ventricular septal defect change their clinical profile with time, but also the differences between the individual groups are not sharp. Obviously there are children with small shunts, others with very large ones, but there is a middle group that is hard to classify accurately except in a most arbitrary fashion. Similarly, it is difficult to define the difference between an uncomplicated ventricular septal defect and a ventricular defect with associated pulmonary stenosis, since the size of the gradient across the right ventricular outflow tract required to have anatomic stenosis varies with the size of the pulmonary flow. Finally, the arbitrariness of assigning numerical values to the cross-section of the pulmonary vasculature and classifying on that basis is self evident.

Once it has been made clear, however, that the division of patients with ventricular septal defect into subgroups is a difficult task, one should consider the other side of the question and recognize that a working classification is necessary for clinical management, including selection of patients for surgery. Consequently, after defining the clinical data of the entire group, the 4 main physiologic subgroups will be summarized and the individuals with aortic regurgitation will comprise a fifth group.

Profile of Patients with Ventricular Septal Defect

Children with ventricular septal defect and left-to-right shunt all have a moderate to loud systolic murmur at the lower left sternal border and rarely at the apex. This murmur can be heard in the vast majority early in infancy. In a large percentage an accompanying thrill is present. A low-frequency diastolic murmur is noted in about three fourths of the children. Left chest prominence is present in about the same proportion of the cases. On the whole, the growth pattern is usually below average. The symptomatology varies a great deal, but it is more severe (with notable exceptions) in infancy. Cardiac enlargement, with pulmonary vascular engorgement characterizes the radiographic picture. The electrocardiogram is usually abnormal; ventricular hypertrophy of one type or another is present in most, and incomplete right bundle-branch block is noted in over 50 per cent of the cases. The prognosis is good, death beyond the neonatal period is rare, and two thirds of the patients are quite stable throughout childhood, some even improving.

Small, Uncomplicated Left-to-Right Shunt. This group most nearly approximates the concept of Roger's disease although even these children have symptoms; however, the symptomatology is milder than in some of the other groups and it does not seem progressive. As to the physical findings, it is worth noting that cyanosis is absent and the second heart sound at the pulmonary area is normal or only slightly accentuated. The heart is of
normal size or is only moderately enlarged, the enlargement involving the right or both ventricles. The main pulmonary artery segment and the left atrium tend to be of normal size. "Hilar dance" is unusual. The electrocardiogram shows normal left ventricular dominance or left ventricular hypertrophy. None of the patients in this group showed right axis deviation or pure right ventricular hypertrophy; P-wave abnormality was very uncommon.

Large Uncomplicated Left-to-Right Shunt. These children have more marked symptoms than those with small shunts. Late appearance of symptoms is not uncommon; all of the patients whose congestive heart failure first appeared after age 4 to 5 years belonged to this category. At physical examination a systolic thrill and an apical diastolic rumbling murmur are almost invariably present, while an early diastolic blowing murmur is not uncommon. The second heart sound at the pulmonary area is frequently accentuated. Electrocardiographic evidence of left ventricular hypertrophy is the commonest finding, though combined hypertrophy and normal left dominance is seen. On x-ray the heart tends to be large with pulmonary vascular engorgement, "hilar dance," left atrial enlargement, and considerable enlargement of the main pulmonary artery.

Ventricular Defect with Pulmonary Stenosis. The symptoms are not unlike those seen in the large left-to-right shunt group. At physical examination the loud systolic murmur and thrill is occasionally noted to be maximal at the upper left sternal border. The second heart sound at the pulmonary area is of normal or decreased intensity in the majority. The electrocardiograms show right or left ventricular hypertrophy and only rarely combined hypertrophy. Radiograms usually reveal a distinctly enlarged heart. Expansile pulsations are uncommon, as are left atrial enlargement and enlargement of the main pulmonary artery segment.

Ventricular Defect with Pulmonary Vascular Obstruction (? Eisenmenger Syndrome). The symptoms in these patients vary from mild to quite severe. At physical examination the systolic murmur is commonly of low intensity and occasionally maximal at the apex. A thrill is less frequent than in the other groups. The second heart sound at the pulmonary area is invariably very loud and an early diastolic blowing murmur is common. The electrocardiogram shows pure right ventricular hypertrophy or combined ventricular hypertrophy in almost every case. At x-ray, cardiac enlargement with pulmonary vascular engorgement is the rule, "hilar dance," left atrial enlargement, and an enlarged main pul-
monary artery segment are frequently seen. The patients with smaller hearts at x-ray probably represent dominantly pulmonary vascular obstruction with only a minimal left-to-right shunt. It is understandable that few examples of this would be seen in our group, since a measurable left-to-right shunt was a prerequisite for being included in the series.

Ventricular Septal Defect with Aortic Regurgitation. The 5 patients with aortic regurgitation accounted for 2 of the 3 patients in this series with subacute bacterial endocarditis and 2 of the 5 with episodes of paroxysmal tachycardia. In general, the symptoms were marked and in one instance were distinctly progressive. At physical examination a characteristic loud to-and-fro systolic-diastolic murmur was heard. The systemic pulse pressure was wide. The electrocardiogram showed marked left ventricular hypertrophy with S-T and T-wave changes in the 4 older children. At x-ray, the heart was markedly enlarged with an unusually prominent aorta. The exclusion of a patent ductus arteriosus even by cardiac catheterization is difficult and may require retrograde aortography or exploratory thoracotomy.

Surgical Considerations

Children with a clinical picture of uncomplicated small ventricular septal defect, i.e., individuals with a small heart and a normal electrocardiogram, should have close periodic re-examinations. Catheterization is not imperative, and operation at the present stage of cardiac surgery with the available information on natural history is not indicated.

Children with at least moderate cardiac enlargement and left ventricular hypertrophy by electrocardiogram represent the group to be considered primarily for operation. These are the individuals with a large left-to-right shunt with or without pulmonary stenosis. Cardiac catheterization followed by surgery should be mandatory as soon as a safe operation is available.

Children with cardiac enlargement and combined ventricular hypertrophy should be catheterized to measure the level of pulmonary vascular resistance and the size of the left-to-right shunt. If the resistance is arbitrarily—below 6 resistance units and the shunt is large, surgery is recommended. In cases with resistance units greater than 12, operation is probably dangerous enough (based on our experience with patent ductus arteriosus and atrial septal defect) to be postponed at least for the time being. The intermediate cases should be judged on their own merits. Children with pure right ventricular hypertrophy, irrespective of heart size, have either associated pulmonary vascular obstruction or pulmonary stenosis. The clinical differentiation between these 2 types should present no real difficulties. Those with pulmonary stenosis are candidates for surgery and those with pulmonary vascular obstruction (with this type of electrocardiogram) probably have too high a resistance to risk operation.

Our experience suggests that not only is the over-all mortality from ventricular septal defect relatively small but also the development or progression of pulmonary vascular disease in small children must be an unusual occurrence. Therefore, there appears to be little point in taking the added risk of surgery in the form of a Dammann operation except in extreme cases.

Summary

1. Ninety-eight patients (average age 6 years) with ventricular septal defect proved at cardiac catheterization were reviewed in detail and summarized in regard to their clinical profile and catheterization data.

2. The various subgroups (uncomplicated small left-to-right shunts, uncomplicated large left-to-right shunts, associated pulmonary stenosis, associated pulmonary vascular disease, associated aortic regurgitation) present a spectrum of physiologic findings each blending into the other; however, each subgroup is clinically recognizable in most instances.

3. The electrocardiogram not only gives considerable information in regard to physiologic diagnosis, but also is useful in selecting patients likely to benefit from surgery.

In the
absence of pulmonary stenosis (clinically recognizable), pure right ventricular hypertrophy almost excludes the possibility of surgery. b. Pure left ventricular hypertrophy is found almost exclusively in suitable candidates for surgery. c. Patients with combined hypertrophy will require cardiac catheterization to determine whether surgery at a reasonable operative risk will be possible.

4. Follow-up data covering 1 to 13 years (average 5 years) on approximately 50 per cent of cases was presented.

5. No clinical evidence for the development or increase of pulmonary vascular disease was noted in this group of children.

6. Late clinical deterioration was noted mainly in those children with large left-to-right shunts without pulmonary vascular obstruction or pulmonary stenosis.

7. A single patient with associated pulmonary stenosis progressed from a large left-to-right shunt to the tetralogy of Fallot syndrome.

8. The prognosis of children with ventricular septal defect appears to be good after infancy for a matter of several years; only 1 child died because of his ventricular defect in this series of 98 catheterized patients.

9. The autopsy data on 5 additional small infants with ventricular defect who died during the period covered by this study are presented.

**SUMMARIO IN INTERLINGUA**

1. Un serie de 98 patientes (etate medie: 6 annos) con defectos ventriculo-septal a demonstracion per catheterisation cardiaca esseva studiata detaliatemente con respecto a lor profili clinic e al datos de catheterisation.

2. Le varie sub-gruppos—non-complicate micre derivationes sinistro-dextere, non-complicate grande derivationes sinistro-dextere, associate stenosis pulmonar, associate morbo pulmono-vascular, associate regurgitation aortica—presenta un spectro de constatationes physiologic con transitiones gradual inter le sub-gruppos. Nonobstante, in le majoritate del casos, le sub-gruppo in question es clinicamente recognoscibile.

3. Le electrocardiogramma provide non solmente importante informationes pro le diagnose physiologic; illo es etiam utile in seliger patientes qui pote beneficiar ab le therapia chirurgic. (a) In le absintia de stenosis pulmonar (clinicamente recognoscibile), hypertrophia dextero-ventricular pur exclude virtualmente le possibilitate de un intervention chirurgic. (b) Hypertrophia sinistro-ventricular pur ocorre quasi exclusivememente in individuos que es bon candidatos pro un intervention chirurgic. (c) Patientes con hypertrophia combinate require catheterisation combinate pro determinar si un intervention chirurgic es possibile sin excessive riscos operatori.

4. Datos de observationes consecutori, colligite durante inter 1 e 13 annos (periodo medie: 5 annos) es presentate pro approximativemente 50 pro cento del casos.

5. Nulle signos clinic del desenvolvimento o augmento de morbo pulmono-vascular esseva notate in iste gruppo de puer e pueras.

6. Tardive deterioration clinic esseva notate principalemente in individuos con grande derivationes sinistro-dextere sin obstruction pulmono-vascular o stenosis pulmonar.

7. Un sol patiente con associate stenosis pulmonar progredeva ab un grande derivation sinistro-dextere al syndrome del tetralogia de Fallot.

8. Le prognose pro juveniles con defecto ventriculo-septal es apparentemente bon pro plure annos post le infantia. Solmente 1 patiente moriva a causa de su defecto ventricular in iste serie de 98 pueros e pueras catheterisate.

9. Es presentate in plus le datos necroptic ab 5 juvenissime infants con defecto ventricular qui moriva durante le periodo coperite per le presente studio.

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VENTRICULAR SEPTAL DEFECT IN CHILDREN


Reports have appeared in the literature which indicate that the long-term use of anticoagulants is effective in preventing recurrent coronary occlusion. On the basis of these results, it has been implied that anticoagulants can be used in patients with impending coronary occlusion with the hope of preventing a frank coronary thrombosis. In this communication, there are described the details in connection with the illness and treatment of 3 patients all of whom had definite premonitory symptoms of an impending coronary thrombosis. The 3 patients were hospitalized immediately after the onset of their symptoms and anticoagulant therapy was initiated in the form of intramuscular injections of 150 mg. of a concentrated aqueous solution of sodium heparin administered at intervals of 8 hours. Under the conditions of this method of administration of anticoagulant therapy, which was considered as completely adequate, all 3 patients developed acute coronary occlusion with typical electrocardiographic changes. One of the patients experienced occlusion after a week of continuous anticoagulant therapy; the other 2 developed the coronary occlusion 48 hours after the start of treatment with anticoagulant. Since hemorrhage, either as a result of rupture of an atheromatous plaque or as a result of intimal changes secondary to intramural hemorrhage because of rupture of vasa vasorum, can precede a coronary occlusion, it is not to be expected on theoretic grounds that anticoagulant therapy can modify or prevent the rupture of these subintimal capillaries and thereby prevent coronary thrombosis with coronary occlusion. This could be an explanation for the failure of anticoagulant therapy to prevent myocardial infarction in the 3 patients described in this report.

WENDKOS
Ventricular Septal Defect in Infants and Children: A Correlation of Clinical, Physiologic, and Autopsy Data
DONALD C. FYLER, ABRAHAM M. RUDOLPH, MARTIN H. WITTENBORG and ALEXANDER S. NADAS

Circulation. 1958;18:833-851
doi: 10.1161/01.CIR.18.5.833

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