Patent Ductus Arteriosus with Pulmonary Hypertension Simulating Ventricular Septal Defect

Diagnostic Criteria in Ten Surgically Proven Cases

By Juan L. Gonzalez-Cerna, M.D., and C. Walton Lillehei, M.D.

The classic findings of a patent ductus arteriosus in a young individual are familiar to most physicians. However, it has been appreciated that several factors, principally pulmonary hypertension or pulmonary artery dilatation in the absence of appreciable hypertension, may significantly alter the classic image and lead to the erroneous diagnosis of ventricular septal defect. In 10 surgically proved cases a patent ductus arteriosus was the sole malformation and so closely simulated a septal defect that extracorporeal circulation was initially considered for each of the patients. Division of the ductus resulted in a complete cure in all 10 patients. Those findings of value in differential diagnosis are analyzed.

The classic picture of patent ductus arteriosus in a young person, characterized by a continuous murmur, loudest over the pulmonary area, bounding peripheral pulses, increased pulmonary vascular markings, and other radiologic evidences of increased pulmonary blood flow, has become generally familiar. Not infrequently, however, patients carrying this congenital malformation do not conform to the classic syndrome. Several factors change the usual features of the disease, of which pulmonary hypertension is one of the most important. Pulmonary hypertension modifies the shunt so that the diastolic component of the murmur is obliterated and the regurgitation of oxygenated blood through the pulmonary valve may lead to the erroneous diagnosis of high ventricular septal defect. Moreover, pulmonary valvular insufficiency due to a marked dilatation of the pulmonary artery may be secondary to a patent ductus arteriosus with a large left-to-right shunt in the absence of appreciable pulmonary hypertension.

Among the patients with congenital heart disease who were surgically treated at the University of Minnesota Hospitals between January 1955 and January 1956, 3 children were referred for open cardiac surgery with the diagnosis of ventricular septal defect with pulmonary hypertension. At the time of operation none was found to have intracardiac lesions. Instead, a patent ductus arteriosus was encountered and divided in all. Each of these patients made a complete recovery with total disappearance of their signs and symptoms. It was recognized in retrospect, that these diagnostic errors resulted from the modified clinical picture of the presence of a moderate or severe degree of pulmonary hypertension. After these earlier experiences, 7 similar patients have been correctly diagnosed preoperatively, and successfully treated. The fact that all of these 7 additional patients were referred to us as septal defects after complete study, including cardiac catheterization, has indicated the need for emphasizing the various diagnostic criteria leading to the suspicion of a patent ductus arteriosus as the sole malformation. We have omitted from this discussion those patients having both a patent ductus arteriosus and a septal defect.

It is the purpose of this report to present data (tables 1 to 4) on these 10 patients with patent ductus arteriosus plus pulmonary hypertension and atypical manifestations, all
of whom were thought by competent cardiologists to have intracardiac lesions.

**REPORT OF CASES**

**Case 1.** This patient's mother had a heart murmur and her mother's sister died during childhood, presumably of a congenital heart defect ("blue baby"). The patient was the product of an uneventful pregnancy and delivery. A rapid heart rate was noted since the first months of life and a heart murmur was detected at the age of 5 months. She subsequently developed easy fatigability and frequent otitis and epistaxis. Cyanosis was never observed.

At the time of admission in January 1955 she was 6 years old, her weight was 18.5 Kg., and her height was 43⅓ inches. The heart was moderately enlarged, no thrills were felt, but a grade III sys-

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**Table 1—Physical Findings**

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Heart size</th>
<th>Thrills</th>
<th>Murmurs</th>
<th>Pulmonary 2nd sound</th>
<th>Blood pressure</th>
<th>Peripheral pulse</th>
<th>Miscellaneous</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Enlarged</td>
<td>Absent</td>
<td>Syst. 3rd L.I.S.</td>
<td>Accentuated</td>
<td>105/50</td>
<td>105/50</td>
<td>Bounding</td>
</tr>
<tr>
<td>2</td>
<td>Enlarged</td>
<td>Absent</td>
<td>Syst. pul. area</td>
<td>Accentuated</td>
<td>95/50</td>
<td>130/70</td>
<td>Normal Mongoloid, high palate</td>
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<tr>
<td>3</td>
<td>Enlarged, precordial bulge</td>
<td>Syst. S.S.</td>
<td>Syst. and L.S.B.</td>
<td>Accentuated</td>
<td>100/60</td>
<td>100/60</td>
<td>Bounding Bilateral cataracts, deafness</td>
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<td>Syst. 3rd L.I.S.</td>
<td>Accentuated</td>
<td>130/60</td>
<td>160/70</td>
<td>Bounding</td>
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<td>5</td>
<td>Enlarged</td>
<td>Absent</td>
<td>Syst. along L.S.B.</td>
<td>Accentuated and duplicated</td>
<td>124/60</td>
<td>124/60</td>
<td>Strong</td>
</tr>
<tr>
<td>6</td>
<td>Enlarged</td>
<td>Syst. S.S. notch and pul. area</td>
<td>Continuous pul. area</td>
<td>Accentuated and duplicated</td>
<td>140/40/0</td>
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<td>Syst. and L.I.S.</td>
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<td>124/60/0</td>
<td>Bounding capillary pulse</td>
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<td>8</td>
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<td>Syst. S.S. notch</td>
<td>Continuous pul. area, diast. apex</td>
<td>Accentuated and duplicated</td>
<td>112/35</td>
<td>112/35</td>
<td>Bounding</td>
</tr>
<tr>
<td>9</td>
<td>Enlarged, precordial bulge</td>
<td>Syst. S.S. notch and aortic area</td>
<td>Syst. aortic area, pul. area</td>
<td>Accentuated and duplicated</td>
<td>110/60</td>
<td>110/60</td>
<td>Soft fem. right radial stronger than left</td>
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<tr>
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<td>Continuous pul. area</td>
<td>Accentuated</td>
<td>95/60</td>
<td>95/65</td>
<td>Normal</td>
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L.S.B. = Left sternal border, L.I.S. = Left intercostal space, S.S. = Suprasternal.
PATENT DUCTUS ARTERIOSUS

Table 2.—Cardiac Catheterization Data in Ten Patients with Patent Ductus Arteriosus Simulating a Septal Defect (Preoperative)

<table>
<thead>
<tr>
<th></th>
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<td>135/65</td>
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<td>8/0</td>
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<td>58/36</td>
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<td></td>
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<td>85/0</td>
<td>85/55</td>
<td>120/75</td>
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<tr>
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<td>14.25</td>
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<td>15.94</td>
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<td>9.3</td>
<td>9.4</td>
<td>10.5</td>
<td></td>
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<td>6</td>
<td>40/3</td>
<td>35/23</td>
<td>94/58</td>
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<td>89.5%</td>
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</table>

*Case 1 was recatheterized postoperatively. Data showed no shunts and normal pulmonary artery pressure.

A soft apical diastolic murmur was heard along the left sternal border, best at the third and fourth interspaces. A pulmonary second sound was louder than the aortic second sound and had a snappy quality. The systemic blood pressure was 105/50 mm Hg and the peripheral arterial pulses were bounding. Roentgenograms were interpreted as showing right ventricular, left ventricular, and left atrial enlargement, prominent and actively pulsating pulmonary artery trunk, increased pulmonary vascular markings, and a small aorta. The electrocardiogram showed left ventricular hypertrophy and left bundle-branch block. Cardiac catheterization in 1954 revealed increases in the oxygen content from the right atrium to the right ventricle to the pulmonary artery and severe pulmonary hypertension. The patient was referred to us by the cardiologists for correction of a presumed ventricular defect.

On February 1, 1955, bilateral anterior thoracotomy with transverse division of the sternum was performed. After the pericardium was opened it was obvious that both the aorta and the pulmonary artery were enlarged; a thrill was felt in the pulmonary artery beginning at the site of the pulmonary valve. The diagnosis was of a ventricular septal defect. The child and a donor were heparinized, their venae cavae and systemic arteries were cannulated, and total cardiopulmonary bypass by means of controlled cross circulation was accomplished. A right ventricular cardiectomy was performed, and an unusually large flow from the open heart was noted immediately. To dry the operative field, the aorta was temporarily occluded just above the coronary ostia, but the left ventricle became distended. At that time oxygenated blood...
flowed back from the pulmonary artery into the right ventricle, indicating passage of blood directly from the aorta to the pulmonary artery. As there was no evidence of a ventricular septal defect or of an aortic-pulmonary septal defect, a patent ductus was immediately diagnosed. The cardiotomy was closed and the extracorporeal circuit was interrupted after 7 minutes 41 seconds of perfusion. Then the area of the ductus was dissected, and a large channel measuring 12 to 15 mm. in diameter was found and divided. The thrill in the pulmonary artery disappeared. Other defects were not encountered. A lung biopsy taken at the operation revealed intimal thickening of the small arteries.

The postoperative convalescence was without complication, no heart murmurs could be heard, the systemic blood pressure was 90/60 mm. Hg, and the patient was discharged on March 4, 1955. Six months after surgery roentgenograms revealed a decrease in the size of the heart and the great vessels and normal pulmonary vasculature. At cardiac catheterization no shunt was demonstrated at any level and the pulmonary artery pressure had regained normal values (20/10 mm. Hg).

Case 2. A 6-year-old girl entered the University of Minnesota Hospitals on March 14, 1955, for surgical treatment of a ventricular septal defect. Her mother had been edematous during pregnancy, but no definite pathology was demonstrated. At the age of 5 weeks a diagnosis of mongolism was made and a heart murmur was discovered. Subsequently slow growth rate, retarded development, frequent upper respiratory infections, and episodes of cyanosis were noted. On admission the diagnosis of mongolism was confirmed, her weight was 16.8 Kg., and her height was 40 inches. The heart appeared to be enlarged and a systolic murmur was present in the area of the pulmonary valve. The pulmonary second sound was accentuated. The blood pressure was 95/50 mm. Hg in the arms and 130/70 in the legs. The femoral pulses were easily palpable. Roentgenography showed considerable cardiomegaly, definite right ventricular enlargement, questionable left ventricular enlargement, and moderate left atrial enlargement. The pulmonary artery segment was prominent, and the central and peripheral pulmonary vasculature was increased. The aorta was considered to be small. The electrocardiogram revealed incomplete right bundle-branch block, prolonged P-R interval, and right ventricular preponderance.

Data from a previous cardiac catheterization disclosed an increase in the oxygen content of the right ventricle, the pressure of which was greatly elevated, in fact, greater than the systolic arterial pressure (table 2). Unfortunately the catheter failed to enter the pulmonary artery, so that pressure and oxygen content could not be determined there. The peripheral arterial blood oxygen saturation was slightly diminished, suggesting an associated right-to-left shunt. A diagnosis of ventricular septal defect with severe pulmonary hypertension was made.

On March 21, 1955 the heart and great vessels were exposed by a bilateral transverse thoracotomy in preparation for open cardiomyotomy. The aorta and the pulmonary artery both appeared enlarged and no thrills were palpated. In view of the large aorta and the experience obtained in case 1, a patent ductus arteriosus rather than a ventricular septal defect was considered. After careful dissection, a large ductus, 15 mm. in diameter, was found. Temporary occlusion of the channel for 15 minutes produced no untoward effects on the heart and circulation; the ductus was then transected. A lung biopsy taken at the operation showed no abnormalities. The postoperative period was uneventful, the only residual physical finding being a very soft systolic murmur in the region of the pulmonic valve. The patient was dismissed from the hospital on April 17, 1955, and has been completely well since.

Case 3. This 6-year-old girl was born from a pregnancy complicated by rubella during the seventh week, and a heart murmur was discovered.

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Heart Size</th>
<th>R.V.</th>
<th>L.V.</th>
<th>L.A.</th>
<th>P.A.</th>
<th>Pulmonary vascularity</th>
<th>Aorta</th>
<th>Fluoroscopic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3'</td>
<td>2'</td>
<td>2'</td>
<td>1'</td>
<td>2'</td>
<td>2' 2'</td>
<td>Small*</td>
<td>Pulsatile aorta</td>
</tr>
<tr>
<td>2</td>
<td>3'</td>
<td>3'</td>
<td>1'</td>
<td>2'</td>
<td>1'</td>
<td>2' 2'</td>
<td>Small*</td>
<td>Pulsatile aorta</td>
</tr>
<tr>
<td>3</td>
<td>2'</td>
<td>2'</td>
<td>1'</td>
<td>N</td>
<td>2'</td>
<td>3' 3' 2'</td>
<td></td>
<td>Very pulsatile aorta</td>
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<td>3'</td>
<td>2'</td>
<td>2'</td>
<td>3'</td>
<td>3' 3'</td>
<td></td>
<td>Pulsatile aorta</td>
</tr>
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<td>3'</td>
<td>2'</td>
<td>1'</td>
<td>4'</td>
<td>4' 1'</td>
<td>N</td>
<td>Pulsatile aorta</td>
</tr>
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<td>1'</td>
<td>2'</td>
<td>2'</td>
<td>3'</td>
<td>3' 3'</td>
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<td></td>
</tr>
<tr>
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</tr>
<tr>
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<td>2'</td>
<td>2'</td>
<td>2'</td>
<td>2'</td>
<td>2' 2'</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>9</td>
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<td>2'</td>
<td>1'</td>
<td>1'</td>
<td>1' 1'</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>10</td>
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<td>3'</td>
<td>N</td>
<td>1'</td>
<td>2'</td>
<td>3' 3'</td>
<td>3'</td>
<td></td>
</tr>
</tbody>
</table>

*Was enlarged at surgery.
N = Normal
1' = Mild
2' = Moderate
3' = Marked
4' = Very marked

Table 3.—Radiologic Findings

GONZALEZ-CERNA, LILLEHEI
at birth. Congenital bilateral cataracts and deafness were found. Slow physical progress, decreased exercise tolerance, frequent upper respiratory infections, and repeated episodes of pneumonia, characterized her clinical picture.

On admission for surgery on January 6, 1956 she was small and slender; her weight was 14.5 Kg. and her height 43 inches. A precordial bulge was seen, a systolic thrill was easily felt along the left sternal border and the suprasternal notch, a grade III systolic murmur was heard best at the third and fourth left interspaces, and a diastolic murmur was heard in the second left interspace. The pulmonary second sound was accentuated, the blood pressure was 100/60 mm. Hg, and the femoral pulses were bounding. Roentgenograms and fluoroscopy revealed moderate cardiomegaly, mainly of the right ventricle, with slight left ventricular and left atrial enlargement. The pulmonary artery segment was prominent, and pulmonary vascularity was distinctly increased. Likewise, the aorta appeared to be enlarged and actively pulsating. The electrocardiogram showed left ventricular hypertrophy. On cardiac catheterization significant increase in the oxygen content from the right atrium to the right ventricle and a greater increase from the right ventricle to the pulmonary artery were found. A moderate degree of pulmonary hypertension was also observed (table 2). From these data two diagnostic possibilities were considered: a ventricular septal defect with streaming into the pulmonary artery and ventricular septal defect associated with a patent ductus arteriosus. To clarify the diagnosis, a retrograde aortogram via the left subclavian artery with 35 per cent Diodrast was performed. The descending portion of the aortic arch was not completely delineated, but no opacification of the pulmonary arteries was seen. Consequently, a patent ductus arteriosus was not demonstrated. She was then referred for intracardiac correction of a presumed ventricular septal defect.

On January 25, 1956, the chest was entered, as in the previous cases. The heart and the great vessels were enlarged. The aorta pulsed actively and a thrill was felt in the right ventricle. The mean pressures in the pulmonary artery and in the aorta were 36 and 71 mm. Hg respectively. The operation proceeded with the cannulation of the left subclavian artery in preparation for cardiopulmonary bypass. Surprisingly, during these maneuvers the tip of the cannula passed into the pulmonary artery through a ductus, which was then immediately dissected and severed. No thrill could then be felt in the right ventricle or pulmonary artery. A biopsy of the left lung showed arteriolar intimal proliferation. The postoperative course was uncomplicated, all murmurs disappeared, and the blood pressure was 106/80. The patient left the hospital on February 12, 1956. Periodic follow-ups have shown that her exercise tolerance is normal and her growth rate has improved.

**Case 4.** This 15-year-old boy was sent from the Philippine Islands for surgical treatment of a ventricular septal defect. He was born after a normal pregnancy. At the age of 1½ years he had a urinary tract infection and anasarca, which apparently responded well to medical management. A heart murmur was first heard at the age of 2½ years. A definite decrease in exercise tolerance and repeated episodes of respiratory infections and pneumonia have characterized his disease. Cardiac catheterization in his home country showed a left-to-right shunt of 4.7 volumes per cent at the ventricular level, with pulmonary hypertension.

On August 8, 1956, physical examination disclosed a prominent precordial region and a large heart. A systolic thrill and a grade IV systolic murmur in the third left intercostal space were noted. In addition, there were a faint apical diastolic murmur and an accentuated pulmonary second sound. The blood pressure in the arm was 130/60 and in the leg 160/70. The femoral arteries pulsed widely. Salient radiologic features were a marked cardiomegaly with predominant right ventricular and left atrial enlargement. The pulmonary vascularity was increased and both the aorta and the pulmonary artery were enlarged and actively pulsating. The electrocardiogram showed biventricular hypertrophy and incomplete right bundle-branch block. Cardiac catheterization at this time revealed a left-to-right shunt at the

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Axis</th>
<th>Ventricular hypertrophy</th>
<th>Atrial enlargement</th>
<th>IRBBB</th>
<th>LBBB</th>
<th>Prolonged P.R. interval</th>
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<td>L</td>
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<td></td>
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IRBBB = Incomplete right bundle-branch block
LBBB = Left bundle-branch block
level of the right ventricle and pulmonary artery, as well as severe pulmonary hypertension (table 2).

On the basis of these data a preoperative diagnosis of a patent ductus was made, and the chest was entered through a left thoracotomy. A large short ductus, 20 mm. in diameter, was found. At this point a 0.1 per cent solution of trimethaphan camphorsulfonate (Arfonad) in 5 per cent dextrose in water was slowly administered intravenously, lowering the systemic blood pressure from 110 to 70 mm. Hg. This reduction of the pressure in the great vessels and the ductus itself considerably facilitated division of the ductus.

The patient's postoperative course was uncomplicated, his general condition gradually improved, and he became completely normal 1 year after the operation. No residual murmurs remain.

Case 5. This 20-year-old woman entered the University of Minnesota Hospitals from a medical center in Southern United States with a diagnosis of an atrial septal defect or atrioventricular communis, based on cardiac evaluation including heart catheterization. She was the product of a normal pregnancy and delivery. From the first year of life she had increasing dyspnea on mild exertion. A heart murmur was heard for the first time at the age of 4 years.

On July 29, 1956 she was a short, obese, white woman weighing 59.5 Kg. Physical examination showed that the heart was enlarged. A grade II systolic murmur was heard along the left sternal border, and the pulmonary second sound was duplicated and greatly accentuated. The blood pressure was 124/60 and the femoral pulses were easily palpated. Roentgenograms revealed marked cardiomegaly with biventricular enlargement, the left atrium being only slightly prominent. The pulmonary artery trunk and the central pulmonary vessels were hugely dilated, whereas the peripheral pulmonary vasculature was only slightly increased. The aorta was of normal or slightly diminished size. The electrocardiogram showed left axis deviation, incomplete right bundle-branch block, and right ventricular hypertrophy. Cardiac catheterization was repeated; a left-to-right shunt at the level of the pulmonary artery and a marked elevation of the pulmonary artery pressure were encountered (table 2). Although the diagnosis of a patent ductus arteriosus seemed obvious, a retrograde aortogram through the left subclavian artery was carried out for confirmation. This study demonstrated simultaneous opacification of the distal aortic arch and the pulmonary vessels. In addition, a ductus diverticulum was also suggested.

On August 13, 1956 a patent ductus arteriosus, 15 mm. in diameter, was found and divided while the blood pressure was lowered from 140 to 60 mm. Hg with the administration of intravenous Arfonad. The patient did well after surgery and no residual murmurs could be heard. She was discharged on August 25, 1956.

Case 6. This 13-year-old girl had been considered healthy until the age of 8 years, when a heart murmur was discovered during a routine physical examination and a patent ductus was diagnosed. In 1952 she was surgically explored in her home country of Brazil but no ductus arteriosus was found. A second catheterization in Brazil revealed pulmonary hypertension, a left-to-right shunt at the ventricular level and a left-to-right shunt at the pulmonary artery level. In addition, the catheter was passed from the pulmonary artery into the aorta. The catheterization report stated that the catheter passed through an aortic septal defect rather than through a patent ductus (no films were taken). Therefore, a diagnosis of an aortic septal defect plus pulmonary valve insufficiency, or an aortic septal defect plus a high ventricular septal defect, was considered. The patient was then sent to us for corrective surgery by means of cardiopulmonary bypass.

On admission, April 23, 1957, physical examination showed her to be a rather slender girl with an enlarged heart and forcible cardiac impulse. A systolic thrill in the upper left sternal border and the suprasternal notch, and a grade III continuous murmur in the pulmonary valve area, were observed. The pulmonary second sound was duplicated and accentuated, the blood pressure was 140/40/0, and the peripheral arterial pulsations were bounding. Radiologic examination showed moderate cardiomegaly, bilateral but predominant left ventricular enlargement, and left atrial enlargement. Both the aorta and the pulmonary artery appeared to be distinctly enlarged and the pulmonary vasculature was engorged. The electrocardiogram revealed left atrial and marked left ventricular hypertrophy. The reported findings on catheterization and thoracotomy seemed so definite that no further special diagnostic studies were carried out by us.

On April 26, 1957 the chest was opened through a bilateral anterior transverse thoracotomy with the pump-oxygenator setup. When the pericardium was opened, no abnormality was found at the root of the great vessels. The area of the ductus was then explored. A large channel was identified, dissected and divided. Arfonad was used to induce hypotension, lowering the systolic blood pressure from 140 to 85 mm. Hg during the clamping of the ductus.

Except for pleural effusion promptly controlled by routine measures there were no postoperative complications. All murmurs disappeared and the blood pressure regained values of 120/85 mm. Hg. The patient was dismissed from the hospital 17 days after surgery.
Case 7. This 11-year-old boy, apparently normal, was first known to have a heart murmur during a routine physical examination in October 1955. Subsequently a slight decrease in exercise tolerance was also noted. In May 1956, appendectomy was performed. He was admitted to the University of Minnesota Hospitals in October 1956, at which time cardiac catheterization was performed (table 2). A diagnosis of ruptured aneurysm of the sinus of Valsalva into the right ventricle was made and he was scheduled for extracorporeal circulation.

The patient was readmitted on August 20, 1957, for intracardiac surgery. Physical examination revealed an enlarged heart, a systolic thrill in the suprasternal notch, and a systolic and diastolic thrill along the left sternal border. On auscultation a grade IV systolic and diastolic murmur was heard in the third left interspace transmitted to the neck and back. The pulmonic second sound was accentuated and duplicated. The blood pressure was 124/60/0 in the arm and 160/60/0 in the leg. A Corrigan type of femoral pulses and a capillary pulse in the nailbeds were observed. Salient radiologic features were marked cardiomegaly, mainly from left ventricular and left atrial enlargement, moderate prominence of the pulmonic artery trunk, and distinct engorgement of the pulmonary vessels. The aorta was massively enlarged and widely pulsatile (fig. 1). The electrocardiogram showed left atrial hypertrophy, incomplete right bundle-branch block, and biventricular hypertrophy. Previous cardiac catheterization had disclosed a left-to-right shunt at the ventricular level and pulmonary hypertension.

At this admission, in the light of the increased experience, several diagnoses were proposed. These were a ruptured sinus of Valsalva aneurysm into the right ventricle, a ventricular septal defect together with aortic regurgitation, or a patent ductus arteriosus associated with pulmonary valve insufficiency. For a clarification of the diagnosis, an aortogram by a catheter inserted retrogradely into the aorta from the left brachial artery was scheduled. The catheter was passed up the aortic arch, and then it was seen to enter the pulmonary artery and the right ventricle. Films taken at this time showed that the catheter had passed through a ductus rather than an aortic-pulmonary septal defect. While the catheter was slowly withdrawn from the right ventricle to the aorta the pressure in the right ventricle was 70/0 mm. Hg, in the pulmonary artery, 70/35 mm. Hg, and in the aorta, 110/70 mm. Hg. Thus injection of contrast material was not deemed necessary.

At operation on August 29, 1957, a large ductus measuring 15 mm. in diameter was found. There was a marked thrill in the pulmonary artery that disappeared on occlusion of the ductus, at which time the blood pressure increased 40 mm. Hg. Induced hypotension with Arfonad lowered the pressure from 160 to 100 mm. Hg. The ductus was then divided.

A lower-left pneumonia complicated the postoperative course but responded well to medical treatment. The patient left the hospital 16 days after surgery, at which time no murmurs were heard.

Case 8. This 4-year-old girl was the product of an uncomplicated pregnancy and delivery. Frequent upper respiratory infections since early life, one episode of pneumonia, and a rapid respiratory rate were reported. A heart murmur was discovered at the age of 2 months. One episode of purpura was adequately controlled. A retrograde aortogram via the left brachial artery taken in 1953 failed to demonstrate a ductus arteriosus. On cardiac catheterization in 1955, a diagnosis of patent ductus arteriosus was established by passing the catheter through it into the descending aorta. However, in addition to a left-to-right shunt at the level of the pulmonary artery, a left-to-right shunt at the ventricular level was
also encountered. Severe pulmonary hypertension was likewise demonstrated. Two diagnostic possibilities were then taken into consideration: a patent ductus arteriosus plus a ventricular septal defect; a patent ductus arteriosus plus pulmonary valvular insufficiency as a result of pulmonary hypertension.

Physical examination on September 15, 1957 revealed a fairly well developed child with a precordial bulge and active precordium. A systolic thrill was felt in the suprasternal notch, and a continuous machinery-like murmur was heard in the pulmonary valve area. In addition, there was an apical diastolic rumbling and the pulmonary second sound was accentuated and duplicated. The blood pressure was 135/35 mm. Hg and the femoral pulses were bounding. Her weight was 16.3 Kg. and her height was 49½ inches. Roentgenograms revealed considerable cardiomegaly, with enlargement of both ventricles and the left atrium. The pulmonary artery trunk was dilated and the pulmonary vascular markings were increased. The aorta appeared normal or relatively small. The electrocardiogram showed left and right ventricular hypertrophy and strain.

The left thorax was opened on September 17, 1957, and a large ductus arteriosus was found. A prominent thrill in the pulmonary artery disappeared upon occlusion and division of the ductus. A lung biopsy obtained at surgery demonstrated only chronic passive hyperemia.

The postoperative course was satisfactory. A grade I systolic murmur at the pulmonic area remained as the only physical finding. The blood pressure was 108/75 mm. Hg. The patient was discharged 2 weeks after the operation.

Case 9. This twin 8-year-old girl was the product of an otherwise normal pregnancy. Her birth weight was 3 pounds, 7 ounces. When she was 3 months old rapid respiration was noted and a heart murmur was discovered. Subsequently, increasing dyspnea on exertion and frequent respiratory infections became apparent. At the age of 7 years she developed an episode of acute nephritis. Her twin sister was known to have had no illnesses.

The patient's cardiovascular condition was evaluated by several means, including cardiac catheterization, at a university hospital in southwestern United States. She was admitted to the University of Minnesota Hospitals on September 16, 1957, for surgical treatment with the diagnosis of ventricular septal defect. Her weight was 17.2 Kg. and her height was 47 inches. Physical examination showed a short, slender girl with a precordial bulge and a systolic thrill in the suprasternal notch and in the second right interspace. A grade IV systolic murmur was heard best at the second right interspace and a short diastolic murmur was heard at the upper left sternal border. The pulmonic second sound was accentuated and duplicated. The blood pressure was 110/60 mm. Hg in the right arm, 100/60 in the left arm, and 70/60 in the lower extremities. The right radial pulse was stronger than the left, and the femoral pulses were soft although easily palpable. Roentgenograms indicated moderate cardiomegaly with predominant left ventricular and left atrial enlargement. The pulmonary artery and the pulmonary vasculature were slightly prominent. On fluoroscopy the aorta was normal in size but pulsed with increased amplitude. The electrocardiogram showed left atrial hypertrophy but no definite ventricular hypertrophy. Cardiac catheterization performed at this time disclosed similar results to those obtained elsewhere. There was a left-to-right shunt at the ventricular level, a left-to-right shunt at the pulmonary artery level, and severe pulmonary hypertension. Two diagnostic explanations were offered: a patent ductus arteriosus plus a ventricular septal defect, or patent ductus arteriosus plus pulmonary regurgitation. Coarctation of the aorta associated with an aortic valve abnormality was also considered a possible condition. A retrograde aortogram via the left subclavian artery showed simultaneous opacification of the aortic arch and large pulmonary arteries.
PATENT DUCTUS ARTERIOSUS

and a large ductus arteriosus and a distinct narrowing of the aorta at the level of the ductus were visualized (figs. 2 and 3).

The patient was operated on through a left thoracotomy. In addition to a ductus measuring 12 mm. in diameter, there was a mild coarctation of the aorta at the level of the ductus. After division of the ductus, pressures were measured in the aorta proximally and distally to the coarctation, the values being 95/68 and 90/75 respectively. Since there was no gradient and no evidence of collateral circulation, it was decided that the minimally coarcted segment should not be excised. The ductus was divided after hypotension had been induced with intravenous Arfonad, the systemic systolic pressure having been lowered from 130 to 80 mm. Hg.

The patient had an uneventful recovery. However, the systolic thrill and murmur persisted unchanged over the suprasternal notch and the aortic area. She was considered to have a residual mild coarctation of the aorta and a bicuspid aortic valve or a mild aortic stenosis. The patient was discharged 11 days after surgery.

Case 10. This twin 2-year-old girl was born prematurely after 6 months and 23 days of pregnancy. Her birth weight was 1,100 Gm., 400 Gm. less than her twin sister’s weight. She developed slowly, had repeated respiratory infections, and suffered two episodes of heart failure and pulmonary edema; the first being when she was 14 months of age, when a heart murmur was discovered and digitalization was instituted. Dyspnea and easy fatigability had also been noted. Her twin sister is apparently normal. This patient was studied at a medical center in Paris, France, in February 1957. At cardiac catheterization the catheter was passed from the pulmonary artery into the descending aorta. Oxygen determinations disclosed a left-to-right shunt at the ventricular level. A moderate degree of pulmonary hypertension was also demonstrated. On the basis of these data a diagnosis of patent ductus arteriosus plus a ventricular septal defect was made. She was referred to the University of Minnesota Hospitals for surgical treatment.

On October 30, 1957, physical examination showed a small and underdeveloped girl. Her weight was 6.5 Kg. and her height was 28½ inches. The heart was enlarged, a systolic thrill was present at the base of the heart, and a grade III continuous murmur was heard best in the pulmonary valve area. The pulmonic second sound was accentuated. The blood pressure was 95/60 in the arm and 95/65 in the leg. The femoral pulses were normal. Roentgenograms and fluoroscopy showed an extremely large heart with distinct right ventricular enlargement and slight left atrial enlargement. Both the aorta and the pulmonary artery appeared dilated and the pulmonary vascularity was considerably increased. The electrocardiograms revealed right atrial enlargement and right ventricular hypertrophy. The diagnoses under consideration were a patent ductus plus pulmonary regurgitation and a patent ductus plus ventricular septal defect, which seemed less likely because of the moderate pulmonary hypertension. A retrograde aortogram was undertaken via the right brachial artery with 76 per cent Renographin. The proximal aortic arch and large pulmonary arteries were simultaneously visualized and a ductus was demonstrated. There was no evidence of pulmonary valve insufficiency.

The patient was operated upon through a left thoracotomy incision. A large ductus arteriosus measuring 10 to 12 mm. in diameter was encountered and transected. The patient had an uncomplicated postoperative course. The murmurs totally disappeared and she was dismissed from the hospital 16 days after the operation.

At operation the main pulmonary artery of this infant was found to be greatly enlarged. This patient illustrates the fact that pulmonary regurgitation associated with a patent ductus arteriosus may occur even in the absence of a severe pulmonary hypertension, which characterized the other cases of this series.

Fig. 3. Lateral projection, case 9. Large ductus arteriosus and mild coarctation of aorta clearly visualized.
Discussion

We have summarized the history and significant physical findings in 10 patients with a left-to-right shunt due to a patent ductus arteriosus, seen at our institution in a 24-month period, all of whom were referred to us for surgical correction of presumed intracardiac lesions. However, each of these patients had a patent ductus arteriosus as the sole malformation responsible for the shunt, and all survived corrective surgery. In 4 patients extracorporeal circulation had been prepared with a consequent loss of valuable operating time. In the first patient of this series, the right ventricle was actually opened before the ductus lesion was recognized.

Subsequent to these chastening experiences in the first 3 patients, our diagnostic acumen has improved to the extent that accurate preoperative diagnosis has been possible in the others, save for the unusual circumstances of case 6.

The fact that 6 of these patients were from widely separated geographic areas indicates that this differentiation has troubled others as well. In fact, conversations with other cardiac surgeons have indicated quite similar experiences.

Thus, it may be worth while to summarize the various signs that have been valuable to us in achieving a correct differential diagnosis between a septal defect and this atypical form of patent ductus arteriosus, with regurgitation of oxygenated blood from the pulmonary artery back into the right ventricle, thus simulating an intracardiac shunt.

History

Gregg,5 Gibson and Lewis,6 and others, have emphasized the definite association often existing between the incidence of maternal rubella during pregnancy and a patent ductus arteriosus. In the presence of a doubtful diagnosis and a patient with such a history (as case 3), cardiac catheterization and retrograde aortography should be performed.

Physical Examination

The murmurs and thrills have not been particularly helpful in the differential diagnosis because of the effects of pulmonary hypertension in lessening the diastolic component of the classic continuous murmur of patent ductus arteriosus.9-11 Moreover, the occurrence of pulmonary diastolic murmur (Graham Steel) in some cases of ventricular septal defect plus pulmonary hypertension12-14 further confuses the picture. However, bounding peripheral pulses and increased pulse pressure should immediately raise suspicion of a patent ductus arteriosus15 even though those findings are obviously also indicative of such other possibilities as ventricular septal defect plus aortic insufficiency,16 ruptured aneurysm of the sinus of Valsalva into the right ventricle,17 arteriovenous fistula of a coronary artery,18 and aortic septal defect.19

Radiologic Findings

As has been well appreciated by many roentgenologists, a left-to-right intracardiac shunt of appreciable magnitude is characteristically associated with a hypoplastic aorta, whereas an extracardiac shunt, such as in patent ductus arteriosus, is accompanied by a large aorta with increased pulsations. This evaluation is facilitated by contrast filling of the esophagus. In infants, in whom a large thymus is frequently present, the interpretation of this sign is usually more difficult.

Electrocardiographic Findings

Usually a small left-to-right shunt through a narrow patent ductus or through a small ventricular septal defect produces no abnormal changes in the electrocardiogram. A wide ductus with a large left-to-right shunt and the consequent overwork for the left ventricle is expressed by the left ventricular hypertrophy. If a significant degree of pulmonary hypertension is superimposed, overburdening of the right ventricle occurs and signs of right ventricular hypertrophy also appear. In ventricular septal defect with increased pulmonary flow and resistance, both left and right ventricular hypertrophy are present. If pulmonary resistance is the salient feature, predominant or isolated right ventricular hypertrophy is generally observed. Thus, the electrocardiogram has offered little
help in the differential diagnosis of these 2 conditions.

Size of the Aorta at Surgery

All the patients of this series were found to have an enlarged aorta at the time of the operation. We believe that whenever this sign is present in a patient undergoing surgery for the correction of a congenital cardiovascular lesion, one should always consider the possibility of a patent ductus arteriosus, either as the sole malformation or combined with an intracardiac shunt. In fact, for some time now in every patient submitted for intracardiac surgery for closure of a ventricular septal defect at our institution the area of the ductus arteriosus is routinely dissected. Fourteen per cent of these patients also had a patent ductus arteriosus and in most cases this condition had not been suspected preoperatively.20

In summary, none of these signs is infallible for differentiating a ventricular septal defect from a patent ductus arteriosus. When there is any doubt in the diagnosis, a retrograde aortogram will usually clarify the question.

If there is evidence of a significant shunt through a patent ductus arteriosus and a possible intracardiac septal defect as well, we prefer to manage these lesions at separate operative procedures for the following reasons: 1. If both lesions are actually present, the preliminary division of the ductus with the consequent reduction in pulmonary hypertension will improve the surgical risk for the later closure of the ventricular septal defect. 2. In an appreciable number of patients, as this series indicates, no intracardiac lesions may be found. Such practice also allows maximum use of the pump-oxygenator by avoiding setting it up for cases in which it is not needed.

Surgical Considerations

Patients with patent ductus arteriosus in whom the manifestations are atypical are characterized, as a group, by larger-than-average channels, a condition which together with the significant pulmonary hypertension usually present, nearly always causes a short, thin-walled, tense ductus. Attempts to ligate such a vessel are dangerous and contraindicated in our opinion. The only treatment to be recommended is division between suitable vascular clamps with suture of the divided ends. This procedure is rendered easier and safer by the temporary reduction of systemic and pulmonary blood pressure by use of a vessel relaxant, such as Arfonad,8 just prior to application of the clamps, and maintained until suturing has been completed. With the systemic blood pressure reduced to a range of 50-75 mm. Hg the great vessels and ductus become soft, slack, and easily manipulated. Physiologically there is virtually no likelihood of complications from such a temporary period of controlled hypotension.

Summary

Ten patients have been described in whom a patent ductus arteriosus with atypical manifestations closely simulated an intracardiac shunt. All 10 patients had a patent ductus arteriosus as their sole lesion, as demonstrated by successful corrective surgery. The diagnostic criteria of value in leading to a correct differential diagnosis in such patients are reviewed and summarized in table 5. The value of utilizing controlled hypotension at the time of surgical division of patent ductus associated with significant pulmonary hypertension is emphasized.

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SUMMARIO IN INTERLINGUA
Es describite dece patientes in quin un patente ducto arterioso con manifestationes atypie simulava fortemente un derivation intracardiae. In omne le dece patientes, le chirurgia corrective—effectuate a bon successo—demonstrava que un patente ducto arterioso esseva le sol lesion. Le criterios diagnostic que es de valor in establir un correcte diagnoses differential in tal patientes es passate in revista e summarisate in tabula 5. Es sublineate le valor del uso de hypotension regulate durante le division chirurgic de patente ductos quae es associate con grados significative de hypertension pulmonar.

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Patent Ductus Arteriosus with Pulmonary Hypertension Simulating Ventricular Septal Defect: Diagnostic Criteria in Ten Surgically Proven Cases
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Circulation. 1958;18:871-882
doi: 10.1161/01.CIR.18.5.871

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