Radiologic Aspects of Operable Heart Disease

VI. Changes Following Surgical Closure of Patent Ductus Arteriosus

By Philip Strauss, M.D., Herbert L. Abrams, M.D., and Saul Robinson, M.D.

The preoperative and postoperative radiologic findings in 71 patients with patent ductus arteriosus treated surgically were investigated. The purpose of the study was to determine the magnitude, character, and rapidity of the changes observed, as well as the relationship of the postoperative change to complicating cardiovascular lesions. Serial examinations were compared with the preoperative studies and with each other, including an analysis of over-all heart size, individual chamber size, the pulmonary vessels, and the aortic silhouette. The results were tabulated and their significance was evaluated.

The preoperative radiologic findings in patent ductus arteriosus have been carefully studied and recorded.1–3 Postoperative radiologic studies, on the contrary, have been few in number, although a number of allusions have been made to the changes noted after ligation.1,4,5 As part of a continuing analysis of the radiologic aspects of operable heart disease, it seemed worthwhile investigating this matter in some detail, in an effort to determine the magnitude, character, and rapidity of the changes observed, as well as the relationship of postoperative change to complicating cardiovascular lesions.

METHODS AND MATERIAL

From a group of 165 consecutive cases of surgically corrected patent ductus arteriosus, 71 patients whose work-up included adequate preoperative and postoperative films were selected for analysis. All roentgen studies had been obtained in deep inspiration, and included posteroanterior, left anterior oblique, right anterior oblique, and lateral projections. Fluoroscopy was routinely employed, except in the immediate postoperative period.

In all cases, a left-to-right shunt through a patent ductus arteriosus was present, and closure of the ductus was undertaken surgically. The age of the patients at the time of surgery is indicated in Table 1. Most patients were followed clinically and radiologically for a period of 1 to 5 years.

The clinical, laboratory, and operative findings were studied prior to radiologic analysis. Thereafter, 2 of the authors assessed on a scale of 0–4+ the size of the pulmonary artery segment, the central or hilar pulmonary arteries, the peripheral pulmonary arteries, the pulmonary veins, the aortic knob, the right atrium, right ventricle, left atrium, and left ventricle. The cardiothoracic ratio and the pulmonary-thoracic ratio* were measured on all preoperative and postoperative examinations. The presence or absence of a convexity at the caudal margin of the aortic knob was noted, and fluoroscopic findings were evaluated. Too few preoperative and postoperative kymograms were available for analysis in this series.

RESULTS

Cardiothoracic Ratio

Cardiothoracic ratio† (C-T ratio) was greater than .50 in 52 patients, and less than .50 in 19. In 50 patients with a C-T ratio above .50, a significant decrease was apparent in the postoperative period (fig. 1). In 2, an increase in the C-T ratio occurred. Among the 19 patients with a ratio of less than .50, a significant diminution occurred in 15. All patients under 10 years of age with an un-

*The pulmonary-thoracic ratio constitutes the ratio of the spine-pulmonic arc distance in centimeters to the transverse diameter of the chest in centimeters (the spine-pulmonic distance is measured from the right lateral margin of the spine at the level of the pulmonary artery segment to the midpoint of an arc drawn at the lateral edge of the pulmonary artery segment, see figure 2).

†The cardiothoracic ratio, although a crude method of evaluating gross cardiac size, seemed useful in comparing preoperative and postoperative films on the same case. While it is true that the cardiothoracic ratio normally diminishes with age, the major change in our patients occurred within the first few months after surgery, and probably represents an effect of the operation.
STRAUSS, ABRAMS, AND ROBINSON

FIG. 1. Patent ductus arteriosus with gross cardiac enlargement. This 16-month-old boy had had many episodes of pulmonary edema prior to admission, and, in spite of medical therapy, congestive heart failure was uncontrollable. Left, Preoperative film. There is massive cardiac enlargement, which in oblique projections was shown to involve both ventricles and the left atrium. The pulmonary vascularity is increased, with large vessels seen at the right base and in the retrocardiac region as well. The aortic knob cannot be defined. The main pulmonary artery is remarkably proliieIlt.

Right. Twenty-five days after operation. A marked decrease in heart size and pulmonary vascularity has occurred. Subsequent films demonstrated further diminution in size.

TABLE 1.—Age of Seventy-one Patients with Patent Ductus Arteriosus at Time of Surgery

<table>
<thead>
<tr>
<th>Age</th>
<th>No. of patients</th>
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<tbody>
<tr>
<td>6—23 months</td>
<td>7</td>
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<tr>
<td>24—59 months</td>
<td>21</td>
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<tr>
<td>5—9 years</td>
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<tr>
<td>10—14 years</td>
<td>12</td>
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<tr>
<td>15 years and older</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>71</td>
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</table>

complicated patent ductus demonstrated a decrease in the C-T ratio postoperatively.

Individual Chamber Size.

Left Ventricle. In 54 of 71 patients there was enlargement of the left ventricle preoperatively. In 45 of these cases, a definite diminution in left ventricular size, usually to normal, was noted during the postoperative observation period.

Left Atrium. Left atrial enlargement was present in 50 of 71 cases. In 40 of these, there was a return to normal size postoperatively. Among the cases showing no definite change, only slight preoperative enlargement had been present in 7.

Right Ventricle. Right ventricular prominence was frequently present. The right ventricle was thought to be enlarged in 50 cases preoperatively, and in 42 of these, it diminished to normal size postoperatively.

Right Atrium. Right atrial size was difficult to evaluate, particularly in the older age group. Of the 14 patients in whom some degree of right atrial enlargement was thought to be present, 6 were below the age of 23 months. When present, right atrial enlargement was accompanied by right ventricular enlargement.

Pulmonary Vessels

Pulmonary-Thoracic Ratio (P-T ratio). The P-T ratio seemed larger than normal in 60 per cent of cases.* In 56 patients, there was a diminution in the P-T ratio after surgery (fig. 2), and in 11 an increase.

Pulmonary Artery Segment. In 65 cases,

*The pulmonary-thoracic ratio in normal subjects ranges from .15 to .25. Age and sex produce no consistent alterations in the P-T ratio.
Fig. 2. Patent ductus arteriosus with large pulmonary flow. This 11-year-old girl had a pulmonary flow 4 times the systemic flow, and a mean pulmonary artery pressure of 57 mm. Hg. Following ductal closure, the mean pulmonary artery pressure dropped to 17 mm. Hg. Left. Preoperative film. The heart, pulmonary artery segment, pulmonary artery branches, and aortic knob are enlarged. The indentation of the barium filled esophagus is prominent. The pulmonary-thoracic ratio is .27. This figure is obtained by dividing (a) the distance in cm. from a line drawn at the right of the spine to a point intersecting the arc of the pulmonary artery segment (5.4 cm.) by (b) the transverse diameter of the chest (20.4 cm.). Right. One week after surgery. The pulmonary artery segment is no longer as prominent as before, the heart size is diminished, and the pulmonary vascularity is decreased. The pulmonary-thoracic ratio is now .24.

Fig. 3. Patent ductus arteriosus with aortic knob convexity in a 4-year-old boy. Left. Preoperative film. There is cardiac enlargement, prominence of the pulmonary artery segment, and increased vascularity. The aortic knob presents a convexity at its caudal surface (arrow). Right. Film obtained 1 year after operation. The bulge in the aortic knob is still visible, and if anything may be somewhat more prominent. The heart and pulmonary vessels have returned to normal size.
the pulmonary artery segment was thought to be unduly prominent. Forty-eight of these demonstrated a definite reduction in the prominence of this segment postoperatively. In 17, no change was observed, and in one the pulmonary artery segment became larger.

**Central Pulmonary Arteries.** In 65 cases, the central (or hilar) pulmonary arteries were increased in size. In 56 of these, a postoperative return to normal was demonstrated.

**Peripheral Pulmonary Arteries.** In 56 cases, enlargement of the peripheral pulmonary arteries was noted. In all but 2 of these, a diminution in peripheral vascularity was observed postoperatively.

**Pulmonary Veins.** Evaluation of the size of the pulmonary veins was far more difficult than recent studies might indicate. Enlargement of the pulmonary veins was thought to be present in only 14 cases. When the pulmonary veins were enlarged preoperatively, not infrequently their enlargement persisted during the postoperative period.

**Aorta**

**Aortic Knob.** Thirty-eight of 71 cases had a prominent aortic knob. In infancy and the early years of life, the aortic knob was difficult to distinguish, and was rarely prominent to a significant degree. In the older groups of patients, however, when the aortic knob could be well delineated, it usually appeared prominent. Following surgery, the aortic knob did not diminish significantly in prominence in most cases, and, in fact, particularly in the younger age groups became more prominent.

**Aortic Knob Convexity Sign.** A convexity just below the aortic knob has been described by Jönsson as a sign of patent ductus arteriosus. This sign, however, is not a reliable indicator of the presence of patent ductus arteriosus, as it may be present in other conditions as well.

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**Fig. 4.** Patent ductus arteriosus with decreased vascularity shortly after surgery. *Left.* Preoperative film. Note the marked increase in central pulmonary artery size, as well as in the size of the peripheral vessels. *Right.* Twelve hours after surgery. A remarkable decrease in the size of the pulmonary vessels has occurred within a short time following surgery.
Patent ductus arteriosus with pulmonary hypertension and markedly elevated pulmonary resistance. This 11-year-old girl had marked pulmonary hypertension, with a pulmonary artery pressure of 99/64, and small bidirectional shunts. The calculated pulmonary resistance was elevated. Following closure of the ductus arteriosus, there was a poor response with intermittent right-sided congestive heart failure persisting over a sustained period of time. She died 10 months after operation in right heart failure. *Left.* Preoperative film. There is cardiac enlargement, a large main pulmonary artery, and prominent central pulmonary artery branches. The peripheral pulmonary branches are relatively small. *Right.* Film obtained 7 months after operation. There has been a marked increase in heart size, and an increase as well in the size of the central pulmonary arteries. The clarity of the peripheral lung fields is relatively striking, and the disparity between central and peripheral vessel size is an indication of the increased resistance in the peripheral pulmonary arterial bed.

**Table 2.—The Aortic Knob Convexity Sign in Patent Ductus Arteriosus**

<table>
<thead>
<tr>
<th>Age</th>
<th>Total no. of patients</th>
<th>Patients with the sign</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No.</td>
</tr>
<tr>
<td>6—23 months</td>
<td>7</td>
<td>0</td>
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<tr>
<td>2—4 years</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>5—9 years</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>10—14 years</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>15+ years</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Totals</td>
<td>71</td>
<td>21</td>
</tr>
</tbody>
</table>

This sign was more prominent in the older age groups than in the younger age groups (table 2). In 20 per cent of cases, it became more pronounced postoperatively than it had been preoperatively, and in some instances it became visible postoperatively when it had not been detected preoperatively.

**Rapidity of Change**

In the immediate postoperative period, the most striking changes observed are a decrease in the peripheral pulmonary vascularity and at times in the size of the hilar pulmonary arteries (fig. 4). Within a matter of hours after surgery, the vessels appear significantly less distended, and by 2 days they have undergone striking regression in size. Two months after surgery, the vessels may appear virtually normal, and beyond 6 months, little alteration in their size may be expected.

The heart size changes at a slower rate. A few days after surgery, some decrease in size may be noted. By 10 days postoperatively, the cardiac silhouette has usually diminished.
somewhat in size, and by 2 months the major change in heart size has already occurred. At 6 months, the heart size has stabilized itself at a point which is rarely changed to any significant degree over the ensuing years. The magnitude of the change is proportional to the preoperative cardiac and pulmonary artery size, which, in turn, probably reflect the volume of the left-to-right shunt. Too few of the patients in this series were catheterized to allow an exact correlation between the size of the shunt and the preoperative appearance of the heart. There was a rough correlation between the size of the ductus as recorded by the surgeon and the degree of preoperative and postoperative roentgen change observed.

**Effect of Pulmonary Hypertension**

If the pressure is high, the shunt large, and the resistance normal or only slightly increased, the pulmonary arteries and heart size return to normal shortly after ductal closure. If the shunt is moderate and the resistance is increased moderately, the heart and pulmonary arteries may decrease in size, but not always to normal. If the shunt is small and the resistance markedly increased, no change in heart size or the appearance of the pulmonary arteries need occur, and indeed progressive enlargement with death in right heart failure may develop (fig. 5).

**Complicating Lesions**

In 13 of the 71 cases, complicating lesions were thought to be present postoperatively either on clinical grounds or on the basis of cardiac catheterization. These consisted of cardiac septal defects, aortic valvular disease, and, in 1 instance, pulmonic stenosis. In general, these were precisely the cases that failed to have the expected alterations in over-all heart size, individual chamber size, and pulmonary artery size during the initial 6-month postoperative observation period.

During the course of study, an apparent correlation between the incidence of second cardiac lesions and the presence of rubella early in pregnancy was incidentally observed. Of 11 patients whose mothers offered a history of rubella early in pregnancy, 6 had definite or very probable second cardiac or great vessel defects. Among 60 cases without a history of maternal rubella, only 9 were thought to have second lesions. This difference is statistically significant.* It is of interest that in patients with a history of maternal rubella, an aortic valvular abnormality (aortic stenosis or aortic insufficiency or both) was the second lesion in almost all cases. Others have made a similar observation.8

**Fluoroscopy**

The major preoperative finding not detectable on roentgenographic examination was the increased amplitude of pulsation of the left ventricle and aorta. In a smaller number of instances, the pulsations of the pulmonary arterial branches were somewhat increased. Fluoroscopic examination after closure of the ductus demonstrated a distinct diminution in the amplitude of pulsation of the left ventricle.

**Discussion**

Donovan et al.,1 found relatively little change in heart size following ductal closure in their series. Only 27 of their patients had postoperative films, however, and the period of roentgenologic follow-up was not described and may have been too short to detect maximal change. Others have noted significant change in heart size following surgery.4 5 Our own experience emphasizes the uniformity with which reduction in heart size may be expected following ductal closure, particularly in patients under the age of 10. Only rarely does any significant regression in heart size or pulmonary vascularity occur beyond 6 months following surgery.

In the roentgenologic follow-up of the postoperative ductus, the question may well arise as to whether or not a persistent murmur is of functional significance. If the cardiac size and the pulmonary vascularity have not returned to normal by 6 months after sur-

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*The chi square of 6.56 indicates that these figures are significant at the 2 per cent level.
surgery, the chances of a significant complicating lesion are relatively high. Under those circumstances further and specialized investigation is warranted.

Virtually all cases of patent ductus arteriosus in this series had definite cardiac enlargement early in life. That a selection factor may be implicated is obvious. Most cases coming to surgery in infancy were in heart failure, which necessitated hospitalization. Obviously, the shunt in these cases was large and the heart size and pulmonary vascularity reflected this.

Of major interest was the fact that many hearts considered "normal" in size preoperatively decreased to a smaller "normal" in size postoperatively. In these cases the ductus arteriosus increased the work load of the heart and caused it to be larger than it would have been in the absence of a left to right shunt, but still well within radiologically normal limits. Similarly, in some instances in which the size of the pulmonary vessels was thought to be within the normal range, a decrease in size was observed. A clinical parallel lies in the observation that many seemingly asymptomatic patients with patent ductus arteriosus experience increased exercise tolerance after ductal closure.

The presence of pulmonary hypertension in association with patent ductus arteriosus is not necessarily a poor prognostic sign, nor need it represent a real increase in pulmonary resistance. If the pulmonary flow is markedly augmented, the pressure may be significantly elevated in the pulmonary artery even though calculated pulmonary resistance is normal. In these cases, the central and peripheral arteries will be enlarged, and the appearance of the pulmonary arteries will suggest increased flow primarily. If the pressure is markedly elevated and the left-to-right shunt is small, this reflects an increase in pulmonary resistance that may imply a poor prognosis (fig. 5). When the pulmonary resistance is thus increased, the size of the central or hilar pulmonary arteries will be increased, but the peripheral pulmonary arteries will be small or normal in size.

This disparity (which can be expressed as a high ratio of central to peripheral artery size) is itself suggestive of pulmonary hypertension associated with elevated pulmonary resistance.9

In a recent attempt to evaluate the roentgen manifestations of pulmonary hypertension in congenital heart disease, Keats et al.10 were able to find a significant disparity (2 – 3+) in respective sizes of central and peripheral arteries on only 14 of 36 cases. A slight (1+) disparity was noted in an additional 9 cases. In their study, however, all patients with pulmonary artery pressure ranging from 30 to 130 mm. Hg were considered as a single group, without considering age (3 to 45 years) or defining pulmonary blood flow or resistance. Under these circumstances, equivocal conclusions might have been predicted because (a) the disparity is a reflection of increased resistance9,11 rather than increased pulmonary flow, and (b) the central pulmonary arteries need not appear enlarged radiologically in children with increased pulmonary resistance9.

The fact that patients with patent ductus arteriosus and markedly elevated pulmonary resistance may do poorly following ductal closure is best illustrated by the experience with those patients who have reversal of flow.12 Surgery in such cases is frequently followed by right heart failure and death. In cases in which the pulmonary resistance is known to be high, but in which some left-to-right shunt persists, attempts at surgical closure probably are justified, even though the prognosis is not as good as in the uncomplicated case. At surgery, and prior to definitive closure, a test period of ductus compression and careful observation of the dynamic changes that ensue is the best method of determining whether closure is practical or whether the patient's well being requires the ductus as an "avenue of escape."

The size of the aortic knob has been suggested as a differential point between patent

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9It is of interest that the youngest case illustrated by Keats et al.9 showing the disparity is a man of 34.
ductus arteriosus and cardiac septal defects.\textsuperscript{3, 7, 18, 14} When a prominent aortic knob is visible, and the radiologic evidence of a left-to-right shunt is conclusive, this sign may be useful in suggesting that a patent ductus arteriosus is more likely than a ventricular septal defect. Its absence, however, should not militate against the diagnosis of a patent ductus arteriosus. This is particularly true in the younger age group, in whom a prominent aortic knob is rarely visible. Above the age of 10, in most instances the aortic knob is prominent and is therefore a more useful diagnostic point at this age. Reliance on the presence of aortic convexity at the site of the ductus is unwarranted in the younger age group, since it is rarely detectable below the age of 4. Above the age of 10 its presence is helpful, but its absence is of no significance in excluding the presence of a patent ductus arteriosus. It was of interest that this sign became significantly more prominent in a number of cases after closure of the ductus. This seemed to be associated with a diminution in the size of the pulmonary artery segment, and hence a sharper delineation of the aortic knob than had previously been possible.

**SUMMARY AND CONCLUSIONS**

Seventy-one cases of patent ductus arteriosus in which surgical therapy was undertaken were analyzed radiologically preoperatively and postoperatively.

A definite diminution in heart size and pulmonary vascularity was observed in a large majority of uncomplicated cases. The most striking early change was in the size of the pulmonary arteries. The diminution in heart size occurred over a somewhat longer period of time.

If the heart size and pulmonary vascularity fail to return to normal by 6 months, a complicating lesion should be suspected.

The aortic knob does not appear enlarged in a significant number of infants with patent ductus arteriosus. Following surgical closure of the ductus, the prominence of the knob may increase significantly.

The environmental factor that correlates best with coronary heart disease is total fat consumption when expressed as a per cent of the total calories. This relationship between total fat intake and coronary heart disease rates for men below 65 may be expressed as follows: populations with fat intakes approximating 40 per cent of their total calories have high death rates; populations with total fat intakes below 20 per cent of total calories have low death rates; populations with intermediate fat intakes have intermediate death rates. Although there are degrees of susceptibility mediated by such unalterable factors such as sex, race, heredity, and body constitution and other environmental factors such as physical activity, obesity, and excessive tobacco, it is clear that the amount and type of fat intake is a major etiologic factor in the pathogenesis of coronary heart disease. Several groups of observers have conclusively demonstrated that feeding diets consisting of highly saturated fats results in high levels of blood cholesterol. Substitution or addition to the diet of certain oils, all naturally rich in unsaturated fatty acids, results in a consistent fall of serum and β-lipoprotein total cholesterol. A deficiency of unsaturated fatty acids, particularly of the essential linoleic, linolenic, and arachidonic acids, results in the formation of a saturated fatty acid-cholesterol complex. This is deposited to a greater extent in the intima of high-pressure arteries. These deposits in the aorta or other large vessels are relatively innocuous but when they are deposited in a strategic position in a coronary vessel, an occlusion or thrombosis may occur. The demonstration that feeding certain marine and vegetable oils containing unsaturated fatty acids causes a fall in serum and β-lipoprotein total cholesterol levels constitutes a major breakthrough for public health that may prove of practical value.
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