Infradiaphragmatic Total Anomalous Pulmonary Venous Connection

By Arnold L. Johnson, M.D., F. W. Wiglesworth, M.D., J. S. Dunbar, M.D., Sarjit Siddoo, M.D., and Maria Grajo, M.D.

A study of 4 cases of uncomplicated total anomalous pulmonary venous drainage, in which the connection with the systemic circuit is in the region of the portae hepatitis, revealed similar clinical and radiologic findings, so that in the fourth case the diagnosis was suspected and confirmed by angioangiographic study. Mainly due to the obstruction of pulmonary venous outflow, this form of total anomalous pulmonary venous drainage forms a distinct entity and the physiologic disturbance is quite different from those anomalies of the venous return in which the connection with the systemic circulation is above the diaphragm.

Total anomalous pulmonary venous return in which the connection with the systemic circuit occurs below the diaphragm forms a separate entity that is in striking contrast with the total anomalous pulmonary venous connections in the thorax. The infradiaphragmatic form is quite distinct, mainly because of partial obstruction to pulmonary venous return in the region of the porta hepatitis. A study of 4 uncomplicated cases in which the common pulmonary vein passed through the diaphragm to join the systemic circulation in the region of the porta hepatitis revealed clinical and radiologic features that permit a reasonable suspicion of the true diagnosis, which may then be established by angioangiographic means. Seventeen cases (table 1) of this variety of anomalous pulmonary venous connection have been found in the literature but no diagnostic criteria have hitherto been established. It should be noted that this type of anomalous pulmonary venous connection may occur in association with a variety of cardiac malformations. These complicated cases are not included in this study, since they do not then represent a clinical entity.

Clinical Findings

In view of the similar anatomic arrangement it is not surprising that the clinical findings in our 4 patients were similar. All were male and age at death was 12 days, 22 days, 22 days, and 23 days (table 2). All were dyspneic and cyanotic. In 1 case, a grade III systolic murmur was heard, maximal in the fourth left intercostal space at the left edge of the sternal border, but no murmur was heard in the remaining 3 cases. The intensity of the pulmonic second sound in the case of D.S. was considered to be normal, while no comment was made regarding this sound in the other 3 cases. The liver was enlarged in 3 cases.

Electrocardiograms obtained in 2 of the cases are compatible with the right ventricular hypertrophy demonstrated at necropsy (fig. 1).

The x-ray examination was of the greatest importance. The appearance of the lungs is an unusual one at this age. There is a reticular appearance due to minute, scattered, irregular areas of increased density. This was seen well in the films of B.F., D.S., and G.W., but in the case of B.O. evidence of pneumonia was present, and this pattern was not evident. In each instance on the films the heart was not

From the Departments of Cardiology, Pathology, and Radiology, The Montreal Children's Hospital and McGill University, Montreal, Quebec, Canada.

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considered to be enlarged or abnormal in contour. Fluoroscopic examination was performed in the case of G.W. and the heart size was seen to be normal and no particular chamber enlargement was evident. In D.S. the right ventricle was considered to be enlarged by this method of examination.

It can hardly be maintained that the radiologic appearance of the lungs is diagnostic for this condition. It may be confused with multifocal pneumonia in the newborn and with conditions included under the heading of the newborn respiratory distress syndromes: hyaline membrane disease, atelectasis of the newborn, amniotic fluid aspiration, and pulmonary hemorrhage. These all produce a diffuse increase in density in the lungs with multiple reticular or punctate shadows. A review of our cases of these conditions has suggested that as a rule the shadows are finer and more uniform than in the cases of infradiaphragmatic pulmonary venous return.

Inasmuch as the correct diagnosis was suspected on the basis of the clinical and x-ray findings in D.S. and supported by angiocardiographic studies, a summary of this case history is presented.

D.S.: Approximately 11 hours after birth this infant became suddenly cyanotic and had considerable respiratory distress and remained so, despite some relief with oxygen therapy, until death on the twenty-second day. There was a

![Fig. 1. Electrocardiograms of D.S. at age 10 days (left) and B.F. at age 12 days (right).](image)

![Fig. 2. Posteroanterior projection of chest in case D.S. at 9 days of age, showing reticulated appearance of lungs.](image)
grade III, moderately harsh systolic murmur, maximal at the fourth intercostal space to the left of the left sternal border. The pulmonic second and the mitral first sounds were normal. The liver remained 3 fingerbreadths below the right costal margin in the midclavicular line. There did not appear to be a definite improvement with digitalization.

The electrocardiogram (D.S. at age 10 days) is shown in figure 1.

On x-ray (fig. 2) there did not appear to be any generalized cardiac enlargement, but on fluoroscopic examination the appearance was suggestive of some right ventricular enlargement. No right or left atrial enlargement was detected. The left aortic arch and the pulmonary artery appeared normal. The hilar vascular markings were average in density and no pulsations were seen in them. The lungs appeared to be overinflated and there were numerous fine, irregular shadows, resulting in

Table 1.—Cases of Uncomplicated Infradiaphragmatic Total Anomalous Pulmonary Venous Return

<table>
<thead>
<tr>
<th>No.</th>
<th>Date</th>
<th>Author</th>
<th>Sex</th>
<th>Age at death</th>
<th>Site of entry of common pulmonary vein</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1916</td>
<td>Ghon</td>
<td>M</td>
<td>15 days</td>
<td>Portal vein</td>
</tr>
<tr>
<td>2</td>
<td>1933</td>
<td>Munck</td>
<td>M</td>
<td>3 mos.</td>
<td>Portal vein</td>
</tr>
<tr>
<td>3</td>
<td>1948</td>
<td>Mykschowsky</td>
<td>M</td>
<td>18 days</td>
<td>Portal vein</td>
</tr>
<tr>
<td>4</td>
<td>1950</td>
<td>Edwards and DuShane</td>
<td>M</td>
<td>9 days</td>
<td>Ductus venosus</td>
</tr>
<tr>
<td>5</td>
<td>1952</td>
<td>Butler</td>
<td>M</td>
<td>2 days</td>
<td>Portal vein</td>
</tr>
<tr>
<td>6</td>
<td>1952</td>
<td>Parsons et al</td>
<td>F</td>
<td>4 wks.</td>
<td>Ductus venosus</td>
</tr>
<tr>
<td>7</td>
<td>1953</td>
<td>Bor</td>
<td>F</td>
<td>10 wks.</td>
<td>Portal vein</td>
</tr>
<tr>
<td>8</td>
<td>1954</td>
<td>Keith et al</td>
<td>M</td>
<td>21 days</td>
<td>Portal vein</td>
</tr>
<tr>
<td>10</td>
<td>1957</td>
<td>Darling et al</td>
<td>M</td>
<td>6 wks.</td>
<td>Portal vein</td>
</tr>
<tr>
<td>11</td>
<td>1957</td>
<td>This series</td>
<td>M</td>
<td>3 wks.</td>
<td>Portal vein</td>
</tr>
<tr>
<td>12</td>
<td>1957</td>
<td>Rosenfeld et al</td>
<td>M</td>
<td>5 wks.</td>
<td>Portal vein</td>
</tr>
<tr>
<td>13</td>
<td>1957</td>
<td>This series</td>
<td>F</td>
<td>4 wks.</td>
<td>Portal vein</td>
</tr>
<tr>
<td>14</td>
<td>1957</td>
<td>This series</td>
<td>M</td>
<td>23 days</td>
<td>Portal vein</td>
</tr>
<tr>
<td>15</td>
<td>1957</td>
<td>This series</td>
<td>M</td>
<td>12 days</td>
<td>Ductus venosus</td>
</tr>
<tr>
<td>16</td>
<td>1957</td>
<td>This series</td>
<td>M</td>
<td>22 days</td>
<td>Portal vein</td>
</tr>
<tr>
<td>17</td>
<td>1957</td>
<td>This series</td>
<td>M</td>
<td>22 days</td>
<td>Region of porta hepatitis</td>
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</tbody>
</table>
a reticulated appearance of the lung fields. It was this appearance, together with the cyanosis, dyspnea, hepatomegaly, and unresponsiveness to digitalization, that suggested the possibility of an infradiaphragmatic anomalous venous connection.

In the angiocardiographic examination (fig. 3 Left) the contrast medium showed early and simultaneous opacification of the aorta and main pulmonary artery, indicating a right-to-left shunt. The pulmonary artery was larger than normal. The contrast medium was widely distributed throughout the pulmonary vascular tree but it was not until 9 seconds after the injection (fig. 3 Right) that a circular shadow appeared below the diaphragm in the region of the porta hepatis. It was evident that there was a significant delay in pulmonary venous return and that at least some portion of the contrast medium had gained this infradiaphragmatic position after the contrast medium had been cleared from the aorta. It could most reasonably have arrived there by way of an anomalous pulmonary venous connection.

On postmortem examination the abnormal findings were confined to the heart and lungs. There was moderate dilatation and hypertrophy of the right atrium and right ventricle (fig. 4) and an aneurysmal bulging of the valvula foraminis ovalis. No pulmonary veins entered the left atrium, which was normal in size, as was also the left ventricle. Two pulmonary veins from each lung joined together to form a common trunk (fig. 5), which lay anterior to the esophagus and passed inferiorly with it and posterior to the heart and through the diaphragm to drain into the left portal vein at the porta hepatis.

The lungs were moderately congested, somewhat rubbery to palpation and only moderately aerated. On microscopic examination there was marked passive congestion of the alveolar walls (fig. 6) with tortuosity and bulging of the capillaries into the alveolar saes and heart failure cells were present. Hemosiderin-laden histiocytes were present in the alveolar walls as well as in the interstitial tissues. The liver showed no evidence of passive congestion and there was no splenomegaly.

**Pathologic Anatomy**

The pathologic features were similar in all 4 cases. There was an increase in the size of the right atrium and the right ventricle in each case, consisting of some dilatation and hypertrophy of each of these chambers. The size of the left atrium and ventricle was probably normal but relatively small in comparison with the right chambers. The valvula foraminis ovalis showed an aneurysmal bulging in D.S., while the other 3 cases showed incompetence of the valvula foraminis ovalis. The pulmonary artery was minimally dilated in 3 cases while in the fourth, B.F., it was not. The aorta was normal in all. The ductus arteriosus was probe-patent in all cases.

There was no patent connection between the pulmonary veins and the left atrium. In 2 cases, however, a solid fibrous cord joined the left atrium to the pulmonary veins near the junction to form the common pulmonary vein (fig. 7). The common pulmonary vein was formed in each instance by the junction of the pulmonary veins from each lung and lay

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**Table 2. Infradiaphragmatic Total Anomalous Pulmonary Venous Return, Clinical Features**

<table>
<thead>
<tr>
<th>Case</th>
<th>Sex</th>
<th>Age (days)</th>
<th>Cyanosis</th>
<th>Dyspnea</th>
<th>Murmurs</th>
<th>Sounds</th>
<th>Liver</th>
<th>X-ray</th>
<th>E.C.G.</th>
</tr>
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<tbody>
<tr>
<td>D.S.</td>
<td>M</td>
<td>23</td>
<td>11 hrs. after birth</td>
<td>+</td>
<td>Grade III S.M. max. fourth LIS</td>
<td>P₂ &amp; M₁ normal</td>
<td>3 fb.</td>
<td>Normal</td>
<td>Reticulated appearance</td>
</tr>
<tr>
<td>B.F.</td>
<td>M</td>
<td>12</td>
<td>At birth</td>
<td>+</td>
<td>None</td>
<td>Not commented upon</td>
<td>At umbilicus</td>
<td>Normal</td>
<td>Reticulated appearance</td>
</tr>
<tr>
<td>B.O.</td>
<td>M</td>
<td>22</td>
<td>At birth</td>
<td>+</td>
<td>None</td>
<td>Not commented upon</td>
<td>2 fb.</td>
<td>Normal</td>
<td>Bilateral pneumonia</td>
</tr>
<tr>
<td>G.W.</td>
<td>M</td>
<td>22</td>
<td>2 days after birth</td>
<td>+</td>
<td>None</td>
<td>Not commented upon</td>
<td>1 fb.</td>
<td>Normal</td>
<td>Reticulated appearance</td>
</tr>
</tbody>
</table>
Fig. 4 Top. Cross section of heart of D.S. on the left with a normal control on the right. The right ventricle is uppermost in both specimens.

Fig. 5 Bottom. Dissection of pulmonary veins and their communications in case of D.S. Lungs above. Liver below. 1. Left pulmonary vein; 2, right pulmonary vein; 3, common pulmonary vein; 4, left portal vein; 5, right portal vein; 6, portal vein; 7, umbilical vein; 8, ductus venosus; 9, inferior vena cava.

anteriorly to the esophagus, passing inferiorly through the diaphragm at the esophageal hiatus. It entered the ductus venosus in the case of B.F., the portal vein in B.O., the left portal vein in D.S., and its site of entry was not definitely determined in G.W. The diameter of the common pulmonary vein in the fixed state was 0.6 cm. just after the union and 0.3 cm. distally near the liver.

The microscopic examination of the lungs showed evidence of subacute to chronic pas-

Fig. 6 Top. Lung showing marked passive congestion with heart failure cells in alveolar sacs. Note thick-walled arteriole to the left of center suggesting presence of hypertension. Contrast with figure 8. Hemalum, phloxin, safron, x190.

Fig. 7 Bottom. Photograph to show the fibromuscular cord connecting the left atrium with the common pulmonary vein (case B.O.). The heart has been turned up opposite the apices of lungs, which are viewed from the posterior aspect. A probe lies in the common pulmonary vein formed by 4 pulmonary veins.
sive congestion. The alveolar walls were thickened as a result of marked congestion of the capillaries, as well as edema. Definite fibrosis could not be demonstrated. There was a moderate degree of hemosiderosis with iron deposited both in the alveolar walls and in the interstitial tissues. The pulmonary arterioles were thick walled with tiny lumens as compared with controls but no measurements were made. In none of the cases was passive congestion of the liver demonstrated.

The fibrous cord joining the left atrium to the common pulmonary vein was serially cross-sectioned and found to consist of areolar tissue and atrial muscle bundles, running longitudinally. No patent or obliterated lumen was found. This presumably is the stem of the common pulmonary vein and suggests that agenesis of the common vein is not necessary for the development of abnormal pulmonary vein drainage.

Circulatory Disturbances

It is difficult to know if the fetal circulation is embarrassed by this malformation. The fact that the pulmonary venous return is small in amount suggests that it might be handled without difficulty. On the other hand, the degree of the right ventricular hypertrophy and the marked microscopic lung changes noted by 12 days of age might indicate that the flow from the lungs suffered significant obstruction prior to birth.

In postnatal life the circulation is seriously impaired by 3 major disturbances. The first is the obstruction provided to drainage of the pulmonary venous return because of the limited cross-sectional area of the common pulmonary vein, ductus venosus, or portal vein. If the flow is into the ductus venosus, all the pulmonary blood flow might pass directly to the inferior vena cava. If, however, the common pulmonary vein enters the portal vein, the pulmonary flow, as previously noted by Edwards and DuShane, might all pass through the liver or might be distributed in part by the way of the hepatic sinusoids and in part by the ductus venosus. It is thus apparent that obstruction provided to pulmonary venous return is similar to that in mitral stenosis, and the microscopic lung sections have shown changes similar to those noted in this valvular obstruction. The second major circulatory disturbance is that all the venous return of the body, both systemic and pulmonary, is handled by the right side of the heart. The third is the occurrence of the right-to-left shunt at the atrial level.

In commenting upon the abnormal circulation in this malformation, Edwards and DuShane noted that the pulmonary congestion is a reflection of the obstruction to pulmonary venous outflow. Because of this stenosis in the pulmonary circuit and the right-to-left shunt, they likened the disturbed circulation to that in a tetralogy of Fallot. It is hard to concur in

FIG. 8 Top. Lung in case of complicated infra-diaphragmatic venous return with pulmonary atresia. Note complete normality of lung as compared with figure 6. Hemalum, phloxin, saffron, X190.

FIG. 9 Bottom. Posteroanterior projection of the chest. B.B.E., age 5 days. Note reduction in the pulmonary vascular markings.
this view when the site of the obstruction makes such a crucial difference in the pulmonary hemodynamics, the pulmonic stenosis of a tetralogy preventing adequate pulmonary inflow, and that of this lesion, like mitral stenosis, preventing adequate pulmonary outflow.

An instructive case in point is provided by our fifth case (B.B.E.) of infradiaphragmatic anomalous pulmonary venous return to the portal vein that was complicated by an atresia of the pulmonary valve with hypoplasia of the pulmonary arteries, and a transposed aorta arising from the right ventricle. It is significant that in the presence of this reduced pulmonary blood flow, the microscopic examination of the lungs (fig. 8) reveals a normal vascular pattern and the absence of heart failure cells and of hemosiderosis. Reduction in the density of the hilar vascular markings, compatible with a reduced pulmonary blood flow, had been apparent in the chest x-ray in this case (fig. 9).

Embryology

The lung bud is differentiated from the ventral surface of the foregut and with its development there occurs an outgrowth from the splanchnic plexus from which the pulmonary veins are formed. The splanchnic plexus has connections with the anterior and posterior cardinal venous systems and with the umbilicovitelline system, so that initially the pulmonary plexus also has these extensive connections above and below the diaphragmatic level. With the growth of the liver, the umbilicovitelline system is gradually differentiated to form the hepatic veins, the liver sinusoids, and the portal vein. Certain hepatic sinusoids are differentiated to form the ductus venosus and provide a direct route for placental blood from the left umbilical vein to the sinus venosus. The common pulmonary vein as shown by Neil12 develops as an outgrowth from the medial superior wall of the left atrium and joins the venous plexus of the developing lung bud. If this union fails to occur, this plexus will drain into a common channel associated with the esophagus and enter the portal venous system by way of the portal vein or ductus venosus.

The presence in 2 of our cases of a fibrous cord extending from the left atrium to the origin of the common pulmonary vein may indicate that there has been a secondary obliteration of the common pulmonary vein between the left atrium and the pulmonary plexus, a possibility suggested by Edwards.12

The other possibility that he noted appears to obtain in the other cases in which no residual structure was found, suggesting that there was agenesis of the common pulmonary vein.

Discussion

The malformation under discussion is not a common one. Over a 23-year period, 1933 to 1955, The Montreal Children’s Hospital autopsy series included 300 cardiac anomalies. Fifteen had total anomalous pulmonary venous return, of which 10 drained into the systemic circuit above the diaphragm and 5 drained infradiaphragmatically. Of the latter, 4 are the cases reported here and the fifth was complicated by the presence of pulmonary atresia, already referred to in connection with the discussion of the changes in the lungs.

The predominant male sex distribution has already been commented upon by Darling.10 In table 1 the sex is known in 16 of the 17 cases and 13 are male. Neglecting the unspecified case the sex ratio in this sample differs from equality at the 2 per cent level. If the unspecified case is a female, the difference is significant only at the 5 per cent level. If it turns out to be a male, the difference is significant almost at the 1 per cent level.*

In the performance of autopsies on infants, it is important always to lift up the apex of the heart to note the position of the insertion of the pulmonary veins, prior to the removal or cutting of these structures. Otherwise the exact details of an anomalous pulmonary venous drainage will be lost forever.

Diagnosis may have a more than academic

*We are indebted to Dr. F. C. Fraser, Director, Department of Genetics, The Montreal Children’s Hospital, for this statistical analysis.
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interest because the mobility, diameter, and length of the common pulmonary vein would allow for an anastomosis to the left atrium, which in our 4 cases, appeared to be of adequate size to accept the pulmonary venous return.

Summary

Four uncomplicated cases of total anomalous pulmonary venous return, in which the connection with the systemic circuit is by a common vein passing infradiaphragmatically to enter in the region of the porta hepatitis, are presented. Reports of 13 previous similar cases were found. This infradiaphragmatic form of anomalous pulmonary venous return is quite distinct from the supradiaphragmatic form because of the partial obstruction to pulmonary venous return, the pathologic findings in the lungs being similar to those of mitral stenosis.

Clinical suspicion of the presence of this lesion is based upon the occurrence of dyspnea and cyanosis in the first few days of life in an infant with an average heart size by x-ray but with a peculiar pulmonary vascular x-ray pattern. Angiocardiography in the 1 case so studied confirmed the diagnosis.

Summary in Interlingua

Es presentate 4 non-complicate cases de anomalous total retorno pulmono-veneso in que le connexion con le circulation systemic es efectutate per un vena commun a passage infradiaphragmatic e entrata in le region del porta hepatic. Esseva trovate reportos de 13 simile casos in le litteratura. Iste forma infradiaphragmatic de anormalitate del retorno pulmono-veneso es clarmente differentiata ab le forma supradiaphragmatic, viste le obstruction partial del retorno pulmono-veneso e le facto que le constatationes pathologic in le pulmones es simile a illos trovate in stenosis mitral.

Le suspicion clinice del presentia de iste lesion es justificate si dyspnea e cyanosis occurre durante le prime dies del vita de un infante con normal dimensiones roentgenologic del corde in association con un roentgenogramma distinctive del vasculatura pulmonal. Angiocardiographia confirmava le diagnoste in le caso unico in que illo esseva usate.

REFERENCES

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