Differential Lung Function in Atrial Septal Defect

By H. A. Fleming, M.D., M.R.C.P.

Studies of atrial septal defect have considered the total pulmonary blood flow and the contribution to the left-to-right shunt made by each lung. No studies have been reported of the separate flows through the 2 lungs. The present study in 25 cases was planned to investigate the differential pulmonary blood flow by bronchspirometry.

Classical studies of atrial defect\(^1\)\(^,\)\(^2\) have mentioned only the total pulmonary blood flow and the appearance of pulmonary plethora on the chest radiograph. No mention has been made of differences between the two lungs.

The present study was suggested by investigations on the first patient in this series. He was a 50-year-old man whose atrial septal defect was confirmed by cardiac catheterization and subsequently repaired under hypothermia. The pulmonary vascular resistance was 4 units (table 1) and the pulmonary blood flow was small for an atrial septal defect. This atypical case presented several difficulties, among which was the difference in the radiographic appearance of vascularity of the 2 lungs (fig. 1). The right lung appeared plethoric and the left oligemic. Angiocardiography confirmed this impression, showing large, well-filled vessels in the right lung and attenuated vessels of normal distribution in the left. Bronchspirometry showed nearly normal distribution of the ventilation and vital capacity but 85 per cent of the oxygen uptake took place in the right lung and only 15 per cent in the left (normal 55 per cent on the right and 45 per cent on the left\(^3\)). Bronchial abnormality was excluded by a normal left bronchogram.

Subsequently the posteroanterior radiographs of several patients with atrial septal defect appeared to show a similar, though less marked, discrepancy between the vascular markings in the 2 lungs. It was thought that there may be a regular difference in the blood flows through the 2 lungs in atrial septal defect and the present study was planned to investigate this point.

When blood samples have been taken from the right and left pulmonary arteries, in cases of atrial septal defect, they have been of identical saturations. Samples from both right and left pulmonary veins have not been obtained frequently and data on their relative saturation are lacking. If it is presumed that they are identical, the blood flows through the individual lungs would be proportional to their oxygen uptakes, which can be measured by bronchspirometry. This presumption should be tested when opportunity offers for sampling from both right and left pulmonary veins in atrial septal defect.

Method

The 25 patients were all adults in the hospital for cardiac catheterization or for repair of their atrial septal defect. The ages ranged from 15 to 51 years. Patients younger than 15 years were not investigated because of the difficulty of manufacturing a Carsens catheter small enough for them. In atrial septal defect the stature is frequently smaller than normal and the larynx is also often relatively small so that it was often necessary to use the smallest catheters made. Cases were otherwise unselected.

Two patients were clinically examples of the ostium primum type of defect in that they had a mitral pansystolic murmur and left axis deviation in the electrocardiogram.\(^4\) Neither diagnosis has yet been confirmed by operation.

All cases but 1, which was so classically an ostium secundum type of defect that catheterization was not considered necessary, have been submitted to cardiac catheterization. This was frequently done within a few days of the bronchspirometry but was never simultaneous with it. The methods used have been described by Wood.\(^5\) Seventeen patients have since had the defect repaired under

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DIFFERENTIAL LUNG FUNCTIONS

TABLE 1.—Data in Twenty-five Cases of Atrial Septal Defect

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age</th>
<th>Sex</th>
<th>Differential lung function % total by right lung</th>
<th>Cardiac catheterization</th>
<th>X-ray</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>O₂ Vent. V.C.</td>
<td>P:B:F P:V.R. P:S.B.F.</td>
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<td>1 A.D.</td>
<td>50</td>
<td>M</td>
<td>85 53 50</td>
<td>5 4 1.2</td>
<td>2.5</td>
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<tr>
<td>2 E.K.</td>
<td>44</td>
<td>F</td>
<td>55 25 43</td>
<td>4 10 2</td>
<td>1.4 54.0</td>
</tr>
<tr>
<td>3 W.T.</td>
<td>28</td>
<td>F</td>
<td>63 59 61</td>
<td>35 &lt;1 7</td>
<td>1.3 71</td>
</tr>
<tr>
<td>4 C.P.</td>
<td>15</td>
<td>F</td>
<td>73 55 66</td>
<td>19 &lt;1 2.5</td>
<td>2 51 7x4</td>
</tr>
<tr>
<td>5 E.M.</td>
<td>33</td>
<td>F</td>
<td>56 44 48</td>
<td>16 &lt;1 3</td>
<td>3 62 5</td>
</tr>
<tr>
<td>6 N.H.</td>
<td>48</td>
<td>F</td>
<td>77 32 48</td>
<td>16 &lt;1 2.5</td>
<td>1 50 4</td>
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<tr>
<td>7 A.I.</td>
<td>47</td>
<td>F</td>
<td>69 40 55</td>
<td>15 &lt;1 5</td>
<td>1 60 4x3</td>
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<td>8 B.E.</td>
<td>23</td>
<td>F</td>
<td>80 40 50</td>
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<td>9 M.H.</td>
<td>40</td>
<td>F</td>
<td>74 68 48</td>
<td>15 &lt;1 4</td>
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<td>10 A.C. (O.P.)</td>
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<td>F</td>
<td>82 46 50</td>
<td>23 1 3.5</td>
<td>1 59 —</td>
</tr>
<tr>
<td>11 K.L.</td>
<td>24</td>
<td>M</td>
<td>65 65 28</td>
<td>— — 1.3</td>
<td>54 —</td>
</tr>
<tr>
<td>12 M.S.</td>
<td>29</td>
<td>F</td>
<td>53 50 52</td>
<td>16 1.3 3.5</td>
<td>1 50 8x4</td>
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<tr>
<td>13 F.N.</td>
<td>51</td>
<td>F</td>
<td>74 30 —</td>
<td>18 &lt;1 3</td>
<td>1.3 50 —</td>
</tr>
<tr>
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<td>F</td>
<td>70 50 —</td>
<td>14 &lt;1 4</td>
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<tr>
<td>15 A.O.</td>
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<td>F</td>
<td>54 47 —</td>
<td>13 &lt;1 4</td>
<td>1.3 69 5x3</td>
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<tr>
<td>16 J.S.</td>
<td>20</td>
<td>M</td>
<td>67 60 —</td>
<td>9 &lt;1 1.5</td>
<td>1 52 —</td>
</tr>
<tr>
<td>17 D.M.</td>
<td>55</td>
<td>M</td>
<td>54 50 —</td>
<td>13 &lt;1 3</td>
<td>1 68 6x5</td>
</tr>
<tr>
<td>18 S.C.</td>
<td>21</td>
<td>F</td>
<td>65 34 —</td>
<td>14 &lt;1 2</td>
<td>1 46 —</td>
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<td>19 A.G.</td>
<td>18</td>
<td>M</td>
<td>56 55 58</td>
<td>14 &lt;1 2.5</td>
<td>1 54 —</td>
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<td>M</td>
<td>60 47 50</td>
<td>22 &lt;1 3.2</td>
<td>1.3 48 2.5</td>
</tr>
<tr>
<td>21 R.H.</td>
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<td>20 &lt;1 3.8</td>
<td>— 68 4x6</td>
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<tr>
<td>22 R.H.</td>
<td>34</td>
<td>M</td>
<td>61 51 50</td>
<td>28 &lt;1 6</td>
<td>2.5 43 3x4</td>
</tr>
<tr>
<td>23 L.P. (O.P.)</td>
<td>38</td>
<td>F</td>
<td>70 60 —</td>
<td>23 &lt;1 5</td>
<td>1.5 51 —</td>
</tr>
<tr>
<td>24 M.N.</td>
<td>23</td>
<td>M</td>
<td>52 53 50</td>
<td>15 &lt;1 3</td>
<td>1.3 55 3</td>
</tr>
<tr>
<td>25 J.H.</td>
<td>19</td>
<td>F</td>
<td>58 68 55</td>
<td>15 &lt;1 2.5</td>
<td>1 46 1.5x2</td>
</tr>
</tbody>
</table>

Average 32 17F 65.5 51.0 51.0 17.3 <1 3.7 1.43 55.2

Standard deviation 9.6 11.4 7.7

O.P., Ostium primum type defect; O₂, oxygen uptake; Vent., ventilation; V.C., vital capacity; P:B:F, pulmonary blood flow (L/min.); P:V.R., pulmonary vascular resistance (units); P:S.B.F., ratio of pulmonary to systemic blood flow; C.T.R., cardiothoracic ratio.

hypothermia by Sir Russell Brock, using the technic described by Ross.⁴ The size of the defect (table 1) and the presence of anomalous pulmonary veins were assessed in these cases. All were examples of the ostium secundum type of defect, 3 being of the sinus venosus variety.³ In the majority of the cases a bilateral thoracotomy permitted examination of both lungs, but latterly a right-sided approach has been used.

Bronchospirometry was carried out in the supine posture with the Carlens catheter and the technic described by Fleming and West.⁵ As already reported,² this method has now been personally used in over 400 cases without ill effect and is a simple and harmless method of investigation.

RESULTS

The chief findings are detailed in table 1. The studies of differential lung function are reported as the percentage of the total function carried out by the right lung. In this series the oxygen uptake varied from 52 to 85 per cent, with an average of 65.5 per cent, that is, from normal to a very considerable increase. In contrast the ventilation and the vital capacity averaged slightly below the normal figure (fig. 2). There was no constant relationship between the oxygen uptake and the ventilation or the vital capacity. Figure 3 shows the traces recorded at bronchospirometry in a case near the average for the series.

The percentage oxygen uptake in the right lung has been plotted against age, size of defect, pulmonary blood flow, systemic blood flow, the ratio of the 2 blood flows, and the cardiothoracic ratio, without any relationships
emerging. It also appeared to be unrelated to the presence of symptoms or to the pulmonary vascular resistance.

**Radiologic Findings**

**Lung Fields.** The vascularity of each lung was independently assessed by 2 observers grading them 0 to 4 on the posteroanterior film. The ratio of the 2 was also estimated. It was soon apparent that this was a very difficult judgment to make, as cardiac enlargement commonly so encroached on the left lung field that little of it was visible for assessment. Fluoroscopy was not helpful. Angiocardiography in 2 cases confirmed the opinion that the increase in vascularity was greater on the right. Figure 4 illustrates an average case in which the peripheral vessels are more marked on the right than the left and in whom 61 per cent of the oxygen uptake occurred on the right side.

The radiologic assessment of the relative vascularity of the 2 lungs correlated poorly with the distribution of the oxygen uptake, but this is not surprising in view of the difficulties mentioned. It should be noted that the attempted radiologic assessment is on an anatomic and not a physiologic basis and need not be closely related to the relative flows in the vessels. When the pulmonary vascular resistance is low, however, an approximate relationship would be anticipated between the appearance of vascularity and the actual flow in the lung.

Postoperatively the lungs appeared radiographically to be of equal and normal vascularity, this usually meaning a reduction in the size of the peripheral vessels on both sides but the right more than the left.

**Heart Size.** The heart size was estimated as a cardiothoracic ratio and an estimate was also made of the relative encroachment on the right and left lung fields. In moderate enlargement the increase was chiefly to the left of the spine, but in greater degrees the right atrium often extended more into the right lung. No precise estimate could be made but there were examples which suggested that particular enlargement to the left was sometimes associated with diminished function of the left lung.

**Operative Findings**

When bilateral thoracotomy was used, the bulk of the right lung was frequently observed to be greater than that of the left. An example of this is shown in figure 5. More marked cases occurred but a photographic record was not made. Similarly, in cases of
anomalous venous drainage of the right upper lobe that lobe occupied a greater than normal volume though the lung was anatomically complete. In such cases the affected lobe or lung was more rigid and filled with more blood than the left lung. Some degree of this difference appears to be common in atrial septal defect but no attempt has been made to relate it to the measured relative pulmonary blood flow.

Lung Fields in Other Cases with Central Arteriovenous Shunts

The posteroanterior radiographs of 15 cases of patent ductus arteriosus and 10 cases of ventricular septal defect were examined. No differences could be seen in the vascular-
the anomalously draining veins were not corrected, would also give interesting information.

**DISCUSSION**

In patients with atrial septal defect it has been established that the ventilation and the vital capacity of the right lung is slightly less than normal and that the oxygen uptake is greater. This increase in the proportion of the oxygen uptake carried out on the right side may be considerable. No completely satisfactory explanation has been reached.

The first factor that has been considered is the relationship of the right pulmonary veins to the atrial septal defect. In the ostium secundum type of defect the right pulmonary veins drain into the left atrium close to the septum and there may be little tissue separating them from the right atrium. If there is anomalous drainage of the right upper lobe, it goes to the right of the septum. These situations are well shown in the figures published by Lewis and others.\(^\text{15}\) It has been demonstrated by dye-dilution technics\(^\text{10, 16}\) that an average of 84 per cent (75 to 97 per cent) of the blood from the right lung crosses the atrial septal defect while only 54 per cent (35 to 75 per cent) of the blood from the left lung does so. It seemed probable that this fact was related to the observations made in this study. It is known that the shunt in atrial septal defect depends on the difference in the filling resistance of the 2 ventricles and that the right is the more distensible.\(^\text{2, 17}\) It was therefore thought possible that with the large volumes of flow concerned, the slightly smaller resistance to outflow from the right lung could encourage the flow on that side, particularly as the vessels are commonly nearly maximally distended. Although in a large atrial septal defect there is no pressure gradient between the 2 atria, in cases in sinus rhythm, a gradient has been demonstrated with differential manometry, from left to right during ventricular systole.\(^\text{18}\) This gradient again would assist the outflow from the right lung.

This explanation of the observations made in this study gains no support from the results obtained from the 2 cases of presumed ostium primum type of defect in which 70 and 82 per cent respectively of the pulmonary blood flow was taking place through the right lung. In this condition the defect is lower and more anterior, so that the right pulmonary veins are not in close relation to it and there may also be an additional shunt at ventricular level. Swan and others\(^\text{16}\) have shown that in this type of defect the mixing of the venous blood from the 2 lungs is nearly complete and there is little preferential shunting of blood from the right lung. This has been commended\(^\text{19}\) as a diagnostic point. In such cases, with the theory advanced, it would be expected that the blood flow, and therefore the oxygen uptake, would be normally distributed between the 2 lungs. The fact that this has not been so in these 2 cases is thought to weaken the thesis. In ostium primum defect, however, the situation of the interatrial communication and its hemodynamic effects vary widely, and until the detailed anatomy in these 2 cases is known, they by no means invalidate the theory. Further studies in proved cases of ostium primum are needed.

Studies in the relationship of the pulmonary vascular resistance to the pressure in the atrium into which the pulmonary veins are draining\(^\text{20-22}\) suggest that raising the atrial pressure lowers the resistance. The atrial pressures studied were all much greater than in the present series and the results are probably not applicable in these cases of
atrial septal defect in which the vessels are usually maximally dilated and tend to behave like a system of rigid tubes.

The second factor considered is the direction of the blood flow in the main pulmonary artery. It seems unlikely that the differential blood flow is related to this, as anatomically it would appear to favor the left rather than the right pulmonary artery. This point is reinforced by the frequency with which post-stenotic dilatation of the left pulmonary artery is seen in pulmonary valve stenosis.

Thirdly, the mechanical effect of the enlarged heart in the left chest was considered. The bulk of the cardiac enlargement is commonly into the left hemithorax so that in the posteroanterior radiograph, much of the left lower lobe is obscured. In this study are several examples of patients with a large heart in the left chest in which the left lung carried an unusually small proportion of the total blood flow. There are also cases of considerable cardiac enlargement, however, with less disturbance of the flow relationship. At bilateral thoracotomy in the supine position, it is common to find the large heart compressing the left lung. If the volume of the heart were a significant factor it might be expected that the ventilation and the vital capacity in the left lung would be affected in similar proportion to the oxygen uptake, but there is a slight tendency in the opposite direction. It is possible that the pressure of the heart on the left lung forces an increased volume of blood into the right lung, thereby decreasing the distensibility of the lung tissue while increasing the oxygen uptake. That this may contain some truth is suggested by the observation at operation that the right lung feels more rigid. It would not explain the increase in volume and rigidity of an anomalously draining lobe.

The problem is presented in the hope that additional evidence may be produced to elucidate the mechanisms involved. Postmortem injection studies of the pulmonary vascular tree would be of interest and it is planned to follow the effect of the repair of the defect on this distribution of blood flow.

**Summary**

In atrial septal defect a greater than normal proportion of the blood flow is through the right lung. This flow may be considerable and can often be suspected from the postero-anterior radiograph and may be confirmed by bronchospirometry. At surgery the right lung or anomalously draining lobes are often found to be unduly voluminous and more rigid than the normally draining lung.

Various explanations for these findings are offered. The most attractive invokes the preferential draining of the blood from the right lung across the defect. A possible objection to this thesis arises in 2 cases of presumed ostium primum defect in which there was also an increased proportion of the flow through the right lung.

The enlargement of the heart into the left chest may also contribute to the situation. It is possible that both these factors are involved.

**Acknowledgment**

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**Summario in Interlingua**

In le presentia de defectos atrio-septal, un plus que normal proportion del fluxo de sanguine passa via le pulmon dextere. Iste fluxo es a vices considerabile. Frequentemente illo pote esser suspicite super le base de radiogrammas postero-anterior e confirmate per bronchspirometria. Al operation il es frequentemente constatate que le pulmon dextere o lobos a drainage anormal es plus voluminos e plus rigide que pulmones a drainage normal.

Es presentate varie explicationes de iste constatazione. Le plus attractive invoca le drainage preferential de sanguine ab le pulmon dextere a transverso le defecto atrio-septal. Un objection possibile contra iste esse presenta le constatation que in 2 casos
de un supponite defecto del ostio prime il etiam habeva un augmentate proportion de fluxo vie le pulmon dextere.

Le allargamento del corde a in le thorace sinistre es forsàn etiam un factor contributori. Il es possibile que ambe le mentionate factores es implicate in le situation.

REFERENCES
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