Partial Pressure of Oxygen Is Lower in the Left Upper Pulmonary Vein Than in the Right in Adults With Atrial Septal Defect*

Difference in PO2 Between the Right and Left Pulmonary Veins

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Background: The right-to-left shunt at the atrial level is responsible for arterial hypoxemia in patients with atrial septal defect.

Objectives: This study investigated the mechanism of arterial hypoxemia in patients with atrial septal defect by measuring the PO2 in both the right and left upper pulmonary veins.

Subjects and method: We prospectively measured the PO2 in the femoral artery and the right and left upper pulmonary veins during cardiac catheterization in 13 adults (median age, 53 years) and 7 children (median age, 7 years) with secundum atrial septal defect. The adults and children were studied consecutively. Contrast echocardiography was performed to evaluate right-to-left shunt in all adults.

Results: Among the children, there were no patients showing arterial hypoxemia, and there was no difference in the PO2 (± SD) between the right and left upper pulmonary veins (right, 100 ± 3.8 mm Hg vs left, 100 ± 7.8 mm Hg; p = 0.92). However, arterial hypoxemia was present in 11 of the 13 adult patients, although contrast echocardiography showed more than a moderate degree of right-to-left shunt in only four adults. The PO2 was lower in the left upper pulmonary vein than it was in the right upper pulmonary vein in all adult patients (right, 91.6 ± 13.8 mm Hg vs left, 73.0 ± 11.5 mm Hg; p < 0.0001).

Conclusion: The PO2 was lower in the left upper pulmonary vein than it was in the right upper pulmonary vein in adults with atrial septal defect. Care must be taken in measuring pulmonary blood flow if the PO2 in the left upper pulmonary vein is low enough to influence oxygen content. The decreased PO2 in the left upper pulmonary vein may contribute to arterial hypoxemia in addition to right-to-left shunt at the atrial level in adults with atrial septal defect.

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Key words: atrial septal defect; intracardiac shunt; PO2; pulmonary vein

Abbreviations: ASD = atrial septal defect; VC = vital capacity; V/Q = ventilation/perfusion ratio

Right-to-left shunt at the atrial level is responsible for decreased saturation of arterial blood in patients with patent foramen ovale and increased venous pressure1,2 or in patients with large atrial septal defect (ASD) and severe tricuspid regurgitation.3 In either situation, there is an assumption that saturation of the right and left pulmonary veins is equally high if arterial hypoxemia is caused only by this reverse shunt. To our knowledge, there has been no report of a comparison between the right and left pulmonary veins regarding PO2.

In the present study, we investigated whether PO2 is equal in the right and left upper pulmonary veins in both adults and children with ASD in order to look for a cause of arterial hypoxemia that is other than the right-to-left shunt.

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### Table 1—Presentation of Data for 13 Adult Patients*

<table>
<thead>
<tr>
<th>No.</th>
<th>Age</th>
<th>Sex</th>
<th>Rhythm</th>
<th>CTR, %</th>
<th>R-Shunt</th>
<th>TR</th>
<th>Qp, L/min</th>
<th>Qs, L/min</th>
<th>PAR, Wood unit</th>
<th>Scinti</th>
<th>Ventilatory Function</th>
<th>P_{O_2}, mm Hg</th>
<th>P_{CO_2}, mm Hg</th>
<th>O_2 content, mL/L</th>
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</thead>
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<td>72</td>
<td>M</td>
<td>Af</td>
<td>73</td>
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<td>3+</td>
<td>4.1</td>
<td>3.0</td>
<td>7.7</td>
<td>M</td>
<td>FEV_{1}/FVC, %</td>
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<td>48</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>59</td>
<td>F</td>
<td>Af</td>
<td>71</td>
<td>2+</td>
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<td>M</td>
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<td>3</td>
<td>73</td>
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<td>SR</td>
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<td>5.2</td>
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<td>% VC</td>
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<td>Af</td>
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<td>1+</td>
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<td>7.1</td>
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<td>M</td>
<td>% VC</td>
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<td>78</td>
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<td>F</td>
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<td>9.4</td>
<td>14.5</td>
<td>M</td>
<td>% VC</td>
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<td>SR</td>
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<td>% VC</td>
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<td>SR</td>
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<td>7.1</td>
<td>4.0</td>
<td>11.2</td>
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<td>% VC</td>
<td>78</td>
<td>102</td>
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<td>74</td>
<td>F</td>
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<td>7.1</td>
<td>4.0</td>
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<td>M</td>
<td>% VC</td>
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<td>68</td>
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<td>M</td>
<td>% VC</td>
<td>77</td>
<td>94</td>
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</tbody>
</table>

* M = male; F = female; Af = atrial fibrillation; SR = sinus rhythm; CTR = cardiothoracic ratio; R-Shunt = right-to-left shunt; TR = tricuspid regurgitation; Qp = pulmonary flow using the right upper pulmonary vein as a reference chamber; Qs = systemic flow; PAR = pulmonary arteriolar resistance; Scinti = V/Q scan of the lung; m = V/Q mismatch; n = normal; (−) = not done; % VC = percent vital capacity; Rt PV = right pulmonary vein; Lt PV = left pulmonary vein; FA = femoral artery.

In the children, there was no arterial hypoxemia and left upper pulmonary vein (right upper pulmonary vein was statistically greater than the right upper pulmonary vein in 5 mL/L in 11 adult patients (Fig. 4). The pulmonary ventilation and perfusion scan by 99mTc macroaggregated albumin in 11 children, if arterial P_{O_2} < 50 mm Hg, was statistically greater than the right upper pulmonary vein in 5 mL/L in 11 adult patients (Fig. 4). The pulmonary ventilation and perfusion scan by 99mTc macroaggregated albumin in 11 adults, if arterial P_{O_2} < 50 mm Hg, was statistically greater than the right upper pulmonary vein in 5 mL/L in 11 adult patients (Fig. 4).

**Results**

The difference in oxygen content (P_{O_2} concentration) was 8.3 L/min when the averages of both upper pulmonary veins were used, whereas the right upper pulmonary vein was measured as 8.3 L/min when the averages of both upper pulmonary veins were used, whereas it was measured as 8.3 L/min when the averages of both upper pulmonary veins were used, whereas the right upper pulmonary vein was used in this study.

In the adults, arterial hypoxemia was present in 11 patients (9.1% of the cases). In the adults, arterial hypoxemia was present in 11 patients (9.1% of the cases). In the children, arterial hypoxemia was present in 5 patients (41.7% of the cases). In the children, arterial hypoxemia was present in 5 patients (41.7% of the cases).

### Materials and Methods

The catheters were easily advanced into the right and left upper pulmonary veins through the ASD. These upper pulmonary veins were identified as right or left when the catheter was superior to the cardiac silhouette such that it would not be contaminated by blood from the cardiac upper veins. In the left atrium, if the bubble was seen entirely in the left atrium, it was discarded as a sampling error. Pulmonary flow using the right upper pulmonary vein was used, whereas the right upper pulmonary vein was measured as 8.3 L/min when the averages of both upper pulmonary veins were used, whereas it was measured as 8.3 L/min when the averages of both upper pulmonary veins were used, whereas the right upper pulmonary vein was used in this study.

In the children, arterial hypoxemia was present in 5 patients (41.7% of the cases). In the children, arterial hypoxemia was present in 5 patients (41.7% of the cases).
the right and left upper pulmonary veins were used. Contrast echocardiography showed that the right-to-left shunt was mild in eight adult patients and that there was no shunt in one patient. During contrast transesophageal echocardiography, no bubble was seen in the left upper pulmonary veins of all 11 adult patients. In two adult patients who had severe reverse right-to-left shunt, acquired cyanosis was seen, and severe tricuspid regurgitation and atrial fibrillation were observed to be present (patients 1 and 4). The mean cardiothoracic ratio was 62%. Both the FEV1/FVC ratio and the percent vital capacity (VC) were normal in five adult patients, and either the FEV1/VC ratio or the percent VC was abnormal in seven adult patients (Fig 5). Five adult patients showed decreased perfusion in the left lung, and one adult patient showed decreased perfusion in the right lung. A ventilation/perfusion (V/Q) mismatch was present in the left lung in four adult patients (patients 1, 2, 4, and 12) and in the right lung in one adult patient (patient 3). There was one adult patient whose perfusion and ventilation were equally disturbed with no V/Q mismatch (patient 9).

**DISCUSSION**

Patients with ASD may become cyanotic with increasing age. This is caused by a reverse shunt through the defect, which is caused by progressive tricuspid regurgitation, which, in turn, is due to pulmonary hypertension. A jet originating from tricuspid regurgitation can cross the ASD, resulting in a right-to-left shunt.

Performing contrast echocardiography by using hand-agitated 5% dextrose in water from peripheral veins, is the most sensitive method for looking for the reverse shunt. We performed contrast echocardiography under normal breathing so as not to enlarge the reverse shunt by straining. In the present study, although the degree of right-to-left shunt was more than moderate in only 4 of the 13 adult patients, arterial hypoxemia was present in 11 adult patients, if arterial PO2 of more than 80 mm Hg is considered normal. Therefore, the degree of arterial hypoxemia seen in the adult group cannot be completely explained by this reverse shunt.

PO2 was lower in the left upper pulmonary vein than in the right pulmonary vein in all of the adult patients, but there was no difference between the right and left pulmonary veins in the children. Therefore, this difference is not congenital but acquired. It is not clear whether this is specific to adult ASD patients, because drawing blood from both pulmonary veins is possible only in the presence of ASD or patent foramen ovale. Hypoxemia in the left pulmonary veins was present in only four adult patients (patients 1, 2, 4, and 12) and in the right pulmonary veins in one adult patient (patient 3).
upper pulmonary vein significantly contributed to arterial hypoxemia in the adult group, because the difference in oxygen saturation between the right and left upper pulmonary veins may derive from the right-to-left shunt being directed to the left upper pulmonary vein. However, because the transesophageal contrast echocardiography, which can visualize the left upper pulmonary vein easily and was performed in 11 of the 13 adult patients, did not show any bubble toward the left upper pulmonary vein during right-to-left shunting in any patient, this possibility is unlikely.

As patients with ASD age, the main pulmonary artery may enlarge and compress the left bronchus, which is progressing pulmonary vascular disease. Pulmonary vascular resistance was > 4 Wood units in 5 of the 13 adult patients. In addition, the increase in heart volume of the left thoracic cavity may collapse that part of the lung, resulting in V/Q mismatch. V/Q mismatch was present in 5 of the 10 adult patients undergoing the pulmonary V/Q scan: in the left lung in four patients, and in the right lung in one patient.

The result of ventilatory function tests in the present study showed that either FEV1/FVC or percentage of VC was abnormal in seven patients, reflecting the above speculation. Hypoxemia in the left upper pulmonary vein was present even in the remaining five patients with normal pulmonary function tests whose cardiothoracic ratio was rather small in comparison with that of patients with abnormal pulmonary function tests. Accordingly, the difference in PO2 between the right and left pulmonary veins cannot be completely explained by this mismatch.

During cardiopulmonary bypass, some blood returns to the left atrium while the aorta is cross-clamped. An abundant network of collaterals has been observed between the bronchial vein and the pulmonary vein in normal lungs obtained at autop
In patients with inflammatory pleuritis, neovascularization can develop from the internal thoracic artery and intercostal arteries and drain into pulmonary veins. Pulmonary veins are also reported as a draining chamber for collaterals derived from portal hypertension. Most of the collaterals reported so far were located in the left pulmonary vein. In the present study, the pulmonary scintigram showed hypoperfusion of the left lung in 5 of the 10 adult patients undergoing pulmonary ventilation and the perfusion scan. This decreased pulmonary blood flow in the left lung may change bronchial circulation after an increase in pulmonary blood flow for a long period of time. The deoxygenated blood, after passing through the capillary phase from the bronchial artery or intercostal artery, might drain into the left pulmonary vein more often than into the right vein.

The difference in $P_{O_2}$ between the right and left upper pulmonary veins caused the difference in the calculation of oxygen content to range from 3 to 34 mL. This difference in oxygen content was sometimes severe enough to influence the measurement of pulmonary blood flow but was often insignificant because the relationship between $P_{O_2}$ and saturation is not linear but sigmoid. When the shunt ratio is measured using oximetry in patients with ASD, blood drawn from either pulmonary vein is used as a reference. This is based on the assumption that the oxygen contents in the right and left pulmonary veins are equal. In the first patient who had severely disturbed pulmonary function, presumably due to increased heart volume and combined pulmonary vascular disease, the calculated pulmonary blood flow was two times greater when the average of the right and left upper pulmonary veins was used as a reference than when only the right upper pulmonary vein was used. The use of average oxygen contents is also based on the assumption that both the right and left pulmonary flows are equal, which was not proved to be correct.

Care must be taken in measuring an intracardiac shunt in patients with ASD if only the right upper pulmonary vein is used as a reference. In addition to right-to-left shunt at the atrial level, decreased $P_{O_2}$ in the left upper pulmonary vein may contribute to decreased arterial $P_{O_2}$.

Study Limitations

We did not offer a very clear explanation as to the cause of this difference; we simply described the phenomenon. Even during thoracic surgery, it is impossible to take blood samples from both pulmonary veins simultaneously when the fraction of inspired oxygen is 20% of the blood. Further study is necessary but can be done only in the presence of an ASD or patent foramen ovale.

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References