Hemodynamic Factors Influencing Arterial Hypoxemia in Massive Pulmonary Embolism with Circulatory Failure

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SUMMARY Arterial hypoxemia is a common finding in acute pulmonary embolism, and its severity is generally assumed to be proportional to the extent of pulmonary artery obstruction. We studied blood gases (during room air breathing and 100% oxygen breathing) and hemodynamic data in seven patients with massive pulmonary embolism and circulatory failure. All measurements were made before and 30 minutes after medical therapy of shock. We observed that a low cardiac output state can result in a misleading improvement in arterial oxygenation during massive pulmonary embolism, and that an improved circulatory status resulting from medical therapy (including inotropic drug infusion with or without blood volume expansion) can paradoxically increase arterial hypoxemia.

We conclude that severity of arterial hypoxemia may not reflect the severity of pulmonary artery obstruction in acute pulmonary embolism if shock is present.

ARterial Hypoxemia is a common finding in acute pulmonary embolism resulting from mismatching of ventilation and pulmonary blood flow. Many authors consider arterial hypoxemia an important diagnostic feature, and its severity is generally assumed to be proportional to the extent of reduction in pulmonary vascular bed.

Because some researchers have found cases of massive pulmonary embolism without arterial hypoxemia, we studied patients suffering from massive pulmonary embolism to examine the effect of a low cardiac output on arterial oxygenation.

Patients and Methods

We studied seven patients (mean age 54 years) suffering from acute massive pulmonary embolism between October 1973 and October 1977. Pulmonary embolism was clinically diagnosed in all cases and was documented by pulmonary angiography (five cases) or autopsy (two cases); in each patient pulmonary embolism induced severe circulatory failure with metabolic acidosis. All patients were intubated and received artificial ventilation with intermittent positive pressure breathing (tidal volume 7 ml/kg, 20 breaths/min) and circulatory failure was managed with inotropic drugs in all patients (dopamine infusion 15 μg/kg/min in six cases and isoproterenol infusion 4 μg/min in one case) and vascular filling (with plasma expanders 20 ml/kg) in three patients. We made hemodynamic measurements just before management of circulatory failure, and after 30 minutes of medical therapy. All patients received urokinase therapy, but only after the second hemodynamic evaluation. Four patients survived (two with medical therapy only, one after emergency embolectomy and one after long-term extracorporeal membrane oxygenation with venoarterial bypass); three patients died despite emergency therapy.

Catheters were inserted to measure the radial artery, right atrial and pulmonary artery pressures; vascular pressures were measured with Statham P23Db transducers positioned at the midaxillary line, and atmospheric pressure was used as a zero reference point. Cardiac output was measured by thermodilution (right atrial injection with temperature recording in the pulmonary artery). Simultaneous sampling of
arterial and venous mixed blood permitted determination of PaO2, PaCO2 and pH by standard electrode technics and measurement of SaO2 and SvO2 by co-oxymetry. Blood gas analyses were performed during room air breathing and after 10 minutes 100% oxygen breathing; arterial and mixed venous Po2, PaO2 and pH were measured with a Delhommé IL Meter 213; hemoglobin saturation (SaO2 and SvO2), was measured with a Delhommé Co-oxymeter IL 182. Arteriovenous difference (DaVo2), oxygen consumption (VO2), and intrapulmonary shunting (Qs/Qt) were calculated.* All measurements were made before medical therapy of circulatory failure and were repeated after 30 minutes of medical therapy (inotropic drug infusion with or without blood volume expansion).

Results

Table 1 summarizes hemodynamic data before therapy for circulatory failure. All patients had a low systemic arterial pressure (54 ± 12 (sd) mm Hg), a low cardiac index (1.3 ± 0.5 l/min/m2) and an enlarged arteriovenous oxygen content difference (9.5 ± 2.4 vol%); mean pulmonary artery pressure and right atrial pressure were high in all cases but one (patient 3), in whom pulmonary embolism was complicated by hypovolemia (massive retroperitoneal bleeding); a metabolic acidosis was present in each patient.

Table 2 summarizes hemodynamic effects of adequate medical therapy (including dopamine infusion in six cases, isoproterenol infusion in one case and blood volume expansion in three cases); mean systemic arterial pressure increased (from 54 ± 12 to 77 ± 18 mm Hg), cardiac index increased (from 1.3 ± 0.5 to 2.1 ± 0.6 l/min/m2) and arteriovenous oxygen content difference narrowed (from 9.5 ± 2.4 to 6.3 ± 1.6 vol%).

Discussion

In pulmonary embolism, the degree of systemic arterial hypoxemia is often assumed to be proportional with the degree of angiographic obstruction.5 Pulmonary embolism causes major inequalities in distribution of pulmonary blood flow; however, it causes

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### Table 1. Hemodynamic Data Before Therapy for Circulatory Failure

<table>
<thead>
<tr>
<th>Case</th>
<th>SAP (mm Hg)</th>
<th>PAP (mm Hg)</th>
<th>RAP (mm Hg)</th>
<th>CI (l/min/m²)</th>
<th>PaO2* (torr)</th>
<th>PaO2 (torr)</th>
<th>DaVO2 (vol%)</th>
<th>Pco2 (torr)</th>
<th>pH</th>
<th>Severity index</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>58</td>
<td>35</td>
<td>13</td>
<td>0.9</td>
<td>115</td>
<td>185</td>
<td>73</td>
<td>12.2</td>
<td>40</td>
<td>7.13</td>
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<td>2</td>
<td>66</td>
<td>36</td>
<td></td>
<td>2</td>
<td>130</td>
<td>116</td>
<td>7.4</td>
<td>32</td>
<td>7.36</td>
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<td>3</td>
<td>35</td>
<td>16</td>
<td>3</td>
<td>1</td>
<td>94</td>
<td>210</td>
<td>58</td>
<td>8.9</td>
<td>28</td>
<td>7.29</td>
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<tr>
<td>4</td>
<td>38</td>
<td>10</td>
<td>2</td>
<td>105</td>
<td>520</td>
<td>69</td>
<td>6.6</td>
<td>35</td>
<td>7.32</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>60</td>
<td>23</td>
<td>13</td>
<td>1.2</td>
<td>75</td>
<td>405</td>
<td>8.9</td>
<td>25</td>
<td>7.32</td>
<td>9</td>
</tr>
<tr>
<td>6</td>
<td>45</td>
<td>24</td>
<td>20</td>
<td>1.1</td>
<td>120</td>
<td>520</td>
<td>83</td>
<td>9.8</td>
<td>23</td>
<td>7.27</td>
</tr>
<tr>
<td>7</td>
<td>52</td>
<td>21</td>
<td>16</td>
<td>1</td>
<td>120</td>
<td>545</td>
<td>59</td>
<td>13</td>
<td>33</td>
<td>7.18</td>
</tr>
</tbody>
</table>

Abbreviations: SAP = mean systemic arterial pressure; PAP = mean pulmonary artery pressure; RAP = right atrial pressure; CI = cardiac index; HR = heart rate; PaO2 = arterial oxygen tension breathing 100% O2; PaO2* = arterial oxygen tension breathing room air; DaVO2 = arteriovenous-oxygen content difference; Pco2 = arterial carbon dioxide tension; severity index = an angiographic obstruction index.14

*QS/QT was calculated using the formula:

\[
\frac{Qs}{Qt} = \frac{C_c' - C_a}{C_c' - C_v}
\]

where \(C_a\) = arterial oxygen content; \(C_v\) = mixed venous oxygen content; and \(C_c'\) = pulmonary capillary oxygen content. \(C_c'\) was calculated using the formula: \(C_c' = (Hb \times 1.34) + (PaO2 \times 0.003)\), where Hb = hemoglobin concentration (g% ml of blood) and the formula: PaO2: Pb - 47 - PaCO2 where Pb = barometric pressure and PaCO2 = arterial carbon dioxide tension.

### Table 2. Hemodynamic Effects of Medical Therapy

<table>
<thead>
<tr>
<th></th>
<th>Before treatment</th>
<th>After 30 min treatment</th>
<th>Paired t test</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAP (mm Hg)</td>
<td>54 ± 12</td>
<td>77 ± 18</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>CI (l/min/m²)</td>
<td>1.3 ± 0.5</td>
<td>2.1 ± 0.6</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>PaO2 (FiO2 = 1)</td>
<td>357 ± 182</td>
<td>218 ± 141</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>PaO2 (FiO2 = 0.21)</td>
<td>68 ± 10</td>
<td>49 ± 3</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>Qs/Qt</td>
<td>9 ± 4</td>
<td>22 ± 9</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>DaVO2 (vol%)</td>
<td>9.5 ± 2.4</td>
<td>6.3 ± 1.6</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Abbreviations: Qs/Qt = physiological shunting; others as in figure 1.
major changes in lung mechanics; these abnormalities result in a partial impairment for oxygen exchange in some lung areas (with a low $\dot{V}A/\dot{Q}$ ratio: "shunt effect") and in a total impairment for oxygen exchange in some others (with $\dot{V}A/\dot{Q} = 0$: "physiological shunting"). Ventilation perfusion imbalance caused by pulmonary embolism explains venous admixture and the usual finding of arterial hypoxemia. Circulatory adjustment in massive pulmonary embolism usually involves a slight increase in cardiac output, and this hemodynamic response worsens ventilation perfusion imbalance because a higher pulmonary blood output must flow through a smaller pulmonary artery tree. Under these conditions the degree of ventilation perfusion imbalance, and then the degree of hypoxemia, is logically proportional to the extent of pulmonary artery obstruction.11

![Figure 1. $P_{\text{aO}_2}$ during air (six-pointed stars) and 100% oxygen (five-pointed stars) breathing is plotted against cardiac index ($CI$) before (closed stars) and after (open stars) treatment (see text). Increase in cardiac index is always accompanied by a decrease in $P_{\text{aO}_2}$.](http://circ.ahajournals.org/)

![Figure 2. Intrapulmonary shunt fraction ($Qs/Qt$) before (open stars) and after (closed stars) treatment is plotted against cardiac index ($CI$). Increase in cardiac index is always accompanied by an increase in $Qs/Qt$.](http://circ.ahajournals.org/)

Except in some cases where arterial hypoxemia results from a right-to-left intracardiac shunting by a patent foramen ovale, hypoxemia in pulmonary embolism usually results from mismatching of ventilation and pulmonary blood flow (ventilation/perfusion imbalance). None of our patients had patent foramen ovale (patent foramen ovale was excluded during angiography or autopsy); therefore, we assumed that they were hypoxemic because of ventilation perfusion imbalance.

Our study indicates that arterial hypoxemia in pulmonary embolism may not always be proportional to the extent of vascular obstruction, especially when pulmonary embolism induces circulatory failure. Our study was performed in seven patients suffering from massive pulmonary embolism with circulatory failure; massive pulmonary embolism was evidenced by pulmonary angiography in five cases (with a severity index of 12 ± 4) or by autopsy finding in two; circulatory failure, caused by right-heart failure (six cases) or hypovolemia (one case), was confirmed by a low systemic arterial pressure and a low cardiac output (table 1); severity of shock was demonstrated by the presence of metabolic acidosis in each patient. Circulatory failure was managed (with inotropic agents and in some cases blood volume expansion), permitting a rapid hemodynamic improvement (table 2) with a rise in cardiac output. In the same time we observed that medical therapy caused wide variations in blood gases; arterial oxygen tension breathing room air and arterial oxygen tension breathing 100% oxygen both decreased when cardiac output increased (fig. 1); physiological shunting (measured during 100% oxygen breathing) increased in each patient when cardiac output increased (fig. 2); carbon dioxide tension was unchanged. Changes in the extent of pulmonary artery obstruction cannot explain the variations in blood gases, since they were observed after a very short time.
and before starting urokinase therapy. We believe that rapid increase in pulmonary blood flow due to medical therapy causes worsening in ventilation perfusion imbalance by recruitment of poorly ventilated areas (with a low VA/Q ratio); similarly, a low cardiac output state during acute massive pulmonary embolism can probably lead to a better matching of ventilation and pulmonary blood flow by derecruitment of poorly ventilated areas (with a low VA/Q ratio).

This study demonstrates that the severity of arterial hypoxemia cannot be related to the extent of vascular obstruction in acute pulmonary embolism with shock.

References

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