CARBON DIOXIDE ACIDOSIS DURING OPEN HEART SURGERY

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SUMMARY

An account is given of severe carbon dioxide acidosis which developed during an open heart operation with cardiopulmonary bypass. This was considered to be due to the uptake of carbon dioxide from a blanket of the gas which was laid over the operating site in an attempt to avoid air embolism. Animal experiments confirmed the source of the acidosis. In comparing the performance of the bag oxygenator with the Melrose oxygenator, no evidence was obtained to suggest that the use of the Melrose oxygenator would have avoided the severe acidosis.

One of the measures which has been advocated for the prevention of cerebral air embolism during open heart surgery is the provision of a blanket of carbon dioxide over the operation site (Myerly, Throckmorton and Gustafson, 1957; Kunkler and King, 1959). Carbon dioxide is heavier than air and lies in the wound. It is very soluble in blood so that if a bubble of the gas enters the arterial tree, the circulation will not be occluded.

The following report describes a case in which this technique produced an unexpected effect.

CASE HISTORY

The patient was a 59-year-old woman of 62 kg, with mitral stenosis and incompetence, who was having a valve replacement under normothermic cardiopulmonary bypass. Anaesthesia was induced with thiopentone and tubocurarine at 8.30 a.m. and maintained with halothane and oxygen. Prior to right thoracotomy, blood gas values were normal (table I). Bypass was started at 9.55 a.m., using a plastic disposable oxygenator (Travenol U 310; Cooley, Beall and Grondin, 1962; fig. 1) with an oxygen flow of 3 l./l. blood flow/min.

Venous return (the blood going from the patient's right atrium to the oxygenator) was poor at first and the patient was given 2 pints of heparinized acid-citrate-dextrose blood rapidly. Following the transfusion, the venous return improved and thereafter bypass was maintained with a pump output of 50 ml/kg body weight/min.

At 9.58 a.m. the left atrium was opened and a stream at 100 per cent carbon dioxide (2 l./min) was directed into the chest wound. Because the perfusion had been poor initially, a degree of metabolic acidosis was anticipated and 100 ml 5 per cent NaHCO₃ was given intravenously.

Further samples of arterial blood were withdrawn at 10.12 a.m. and 10.40 a.m. but these results were not available until 11 a.m. when the following values were reported:

<table>
<thead>
<tr>
<th>Time (a.m.)</th>
<th>pH</th>
<th>CO₂ tension (mm Hg)</th>
<th>Standard bicarbonate (m.equiv./l.)</th>
<th>O₂ sat. (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.12</td>
<td>6.98</td>
<td>200</td>
<td>18</td>
<td>89</td>
</tr>
<tr>
<td>10.40</td>
<td>7.05</td>
<td>120</td>
<td>19</td>
<td>91</td>
</tr>
</tbody>
</table>

Another arterial sample was taken and the high carbon dioxide tension and low pH confirmed.

At 11.20 a.m. the left atrium was closed and the carbon dioxide turned off. When bypass was stopped at 11.30 a.m., the heart maintained the circulation without difficulty. Apart from a pre-existing atrial fibrillation, the electrocardiogram was normal, as it had been throughout the operation. Analysis of arterial samples taken at this stage showed that there had been a marked fall in carbon dioxide tension and a rise in pH (table I).

During the afternoon and evening the patient's condition was satisfactory. She was fully conscious, her blood pressure was well maintained and her breathing, which was assisted by a Bird ventilator through an endotracheal tube was satisfactory. Blood gas analyses (table I) showed that there was only a mild degree of respiratory acidosis.

At 9 a.m. on the morning after operation the endotracheal tube was removed. Over the next three hours, however, she had considerable difficulty in coughing up her secretions. A tracheostomy was performed under light general anaesthesia at midday, a quantity of blood-stained mucoid secretions removed, and respiration was again assisted by a ventilator.

One hour later, while her tracheobronchial tract was being aspirated, she became cyanosed and lost consciousness. On being ventilated, her colour improved but her level of consciousness did not. Thereafter, despite controlled ventilation with normal blood pressure and normal blood gas levels, her level of consciousness deteriorated and she died the next
morning, 48 hours after the operation. Post mortem examination revealed widespread cerebral damage of the type caused by an acute hypoxic episode.

EXPERIMENTAL STUDIES
The profound acidosis and the high carbon dioxide tension which occurred in the patient during bypass were quite unlike anything previously observed in patients without a carbon dioxide blanket. It seemed reasonable, therefore, to attribute them to the use of the carbon dioxide blanket and experiments were carried out to test this hypothesis.

The conditions of the operation were reproduced in a dog of 20 kg weight. A plastic bag oxygenator (Travenol U 330) was used, with a blood flow of 50 ml/kg body wt/min and an oxygen flow of 3 l./l. blood flow/min. Blood was sampled from the venous return line, from the cardiotomy suction line and from the outflow line to the dog's femoral artery (as in fig. 1). After control values had been obtained, the chest wound was flooded with 100 per cent carbon dioxide (2 l./min) and further samples taken.

The results are summarized in table II which shows that the blood in the cardiotomy suction line initially had a lower carbon dioxide tension than the blood in the venous return line. However, when the carbon dioxide was turned on, the blood in the cardiotomy suction line in the left side of the heart had a very much greater carbon dioxide tension than the blood in the venous return line. The carbon dioxide tension of the blood leaving the oxygenator showed a much smaller increase (table II).

![Diagram of bag oxygenator](https://academic.oup.com/bja/article-abstract/36/12/793/262168/2072168)
CARBON DIOXIDE ACIDOSIS DURING OPEN HEART SURGERY

Table II

Data from dog experiment.

<table>
<thead>
<tr>
<th>Time (min) and stage</th>
<th>Inflow to oxygenator</th>
<th>Cardiotomy suction line</th>
<th>Outflow from oxygenator</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pH</td>
<td>Carbon dioxide tension (mm Hg)</td>
<td>pH</td>
</tr>
<tr>
<td>0 Bypass started</td>
<td>7.31</td>
<td>38</td>
<td>7.47</td>
</tr>
<tr>
<td>5 Control readings</td>
<td>7.27</td>
<td>14</td>
<td>7.36</td>
</tr>
<tr>
<td>10 Control readings</td>
<td>7.14</td>
<td>62</td>
<td>6.67</td>
</tr>
<tr>
<td>15 CO₂ blanket on</td>
<td>7.09</td>
<td>78</td>
<td>6.65</td>
</tr>
</tbody>
</table>

*Approximate values.

Secondly, the efficiency of the plastic bag oxygenator in eliminating carbon dioxide was tested and compared with that of a Melrose oxygenator. Two bags (Travenol U310) were connected in series, with the output of one leading into the input of the other. The bags were primed with acid-citrate-dextrose blood to which sodium bicarbonate had been added to bring the standard bicarbonate to 35 m.equiv/L. Carbon dioxide/oxygen mixtures of varying composition were then bubbled through the first bag which represented a patient, producing blood with varying carbon dioxide tensions. Oxygen was bubbled through the second bag in the usual way (i.e. 3 l./min, blood flow/min) and the carbon dioxide tension of the blood entering and leaving the second bag determined. The blood flow was 3 l./min.

A Melrose oxygenator was then put into the circuit in place of the second bag oxygenator and the carbon dioxide tension in the blood entering and leaving the Melrose oxygenator determined. A 2½ per cent carbon dioxide in oxygen mixture was employed for oxygenation in the Melrose machine.

The results are shown in table III. The amount of carbon dioxide removed by either oxygenator depended on the carbon dioxide tension of the blood entering the oxygenator. There was no evidence that the bag oxygenator was less efficient in removing carbon dioxide than the Melrose oxygenator.

Finally, the carbon dioxide blanket was used for shorter periods at the critical stage of the operation in an attempt to give protection against air embolism without producing a carbon dioxide acidosis. In six patients the carbon dioxide blanket was used for periods of 5–10 minutes as the chambers of the heart were being closed and, although the carbon dioxide tension of the patient's arterial blood increased on each occasion, in none did it exceed 90 mm Hg. Blood in the cardiotomy suction line, however, had a high carbon dioxide tension, and the pH of this blood was 6.75 on one occasion.

Table III

Elimination of carbon dioxide by bag oxygenator and by Melrose oxygenator.

<table>
<thead>
<tr>
<th>Oxygenator</th>
<th>Sample</th>
<th>Input</th>
<th>Output</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bag</td>
<td>1</td>
<td>47</td>
<td>37</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>105</td>
<td>60</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>155</td>
<td>68</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>160</td>
<td>70</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>180</td>
<td>72</td>
<td>108</td>
</tr>
<tr>
<td>Melrose</td>
<td>1</td>
<td>39</td>
<td>33</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>170</td>
<td>96</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>180</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>190</td>
<td>105</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>235</td>
<td>120</td>
<td>115</td>
</tr>
</tbody>
</table>

Results are expressed as blood carbon dioxide tension (mm Hg)

Discussion

The use of a blanket of carbon dioxide to prevent air embolism was advocated because its solubility in blood is much greater than that of oxygen or nitrogen. Its use for this purpose, however, is not without potential danger. Campbell and Owen
(unpublished observation) have shown that large quantities of carbon dioxide can be taken up by blood very rapidly. Exposed to pure carbon dioxide, 10 ml of blood will take up as much as 12 ml of carbon dioxide and this will lower the pH to 6.4.

There is little doubt that the carbon dioxide blanket was responsible for the low pH and high carbon dioxide tension observed in this patient. Data from the dog experiment and from cases in which a carbon dioxide blanket was used for a short period showed that blood sucked off in the cardiotomy line had a high carbon dioxide tension and low pH. Uptake of carbon dioxide would have occurred not only in the blood exposed directly to carbon dioxide in the chest wound but also, and to a greater degree, in the cardiotomy line through which blood and carbon dioxide were sucked from the operating site.

In comparing the performance of the bag oxygenator and the Melrose oxygenator, no evidence was obtained to suggest that the use of the Melrose machine would have avoided the severe acidosis. In other bypass operations in which either oxygenator was used without a carbon dioxide blanket, the carbon dioxide tension of the patient's arterial blood was normal or low. However, the limited experimental data suggest that neither oxygenator will maintain an adequately low carbon dioxide tension (40 mm Hg or less) in the arterial blood when the carbon dioxide tension of the blood entering the oxygenator is high.

The post mortem examination of the patient revealed widespread cerebral damage of which there are a number of possible causes (Lancet, 1964). The most likely was the hypoxic episode which occurred during tracheobronchial suction. It is impossible to decide whether the high carbon dioxide tension was a contributory factor. Severe carbon dioxide retention is generally regarded as undesirable, dangerous or even lethal. However most patients with severe carbon dioxide retention have also hypoxaemia.

The tolerance of humans to a high carbon dioxide tension in the presence of adequate oxygenation has been noted by various authors (Stephen, Bourgeois-Gavardin and Dent, 1959; Schultz et al., 1960; Altschule, 1962); Clowes, Hopkins and Simeone (1955) administered 30–35 per cent carbon dioxide to anaesthetized patients for periods of up to 26 min producing minimum pH values of the range 6.8–7.1 but without causing harm. Others (Brown and Miller, 1952; Holmdahl, 1956; Broom, 1962) have reported the absence of ill effects of high carbon dioxide tensions in animals.

Nevertheless, until further information is available it would be prudent to avoid the production of high carbon dioxide tensions in patients undergoing bypass surgery. At the same time it would seem reasonable to use a carbon dioxide blanket but only for short periods and only when biochemical monitoring is available. By this means the value of the procedure as a protection against air embolism could be assessed with minimum risk to the patient.

ACKNOWLEDGMENTS

We wish to thank Mr. D. Wade for help in the dog experiment and we are grateful to Miss N. Percy and Miss T. Ybema for blood gas analyses.

REFERENCES


ACIDOSIS PAR LE DIOXYDE DE CARBONE AU COURS DE LA CHIRURGIE À COEUR OUVERT

SOMMAIRE
On rapporte un cas d'acidose sévère par le dioxyde de carbone qui s'est développé au cours d'une opération à cœur ouvert avec bypass cardio-pulmonaire. On pense que cette complication était due à une certaine quantité d'oxyde de carbone provenant d'une nappe de gaz installée au-dessus du plan opératoire pour essayer d'éviter une embolie gazeuse. Des expériences sur l'animal ont confirmé cette source d'acidose. En comparant le débit de l'oxygenateur à ballon avec celui de la machine de Melrose on n'obtient pas d'argument prouvant que par l'utilisation de l'oxygenateur de Melrose on aurait pu éviter cette acidose sévère.

Kohlendioxyd-Azidose während offener Herzchirurgie

ZUSAMMENFASSUNG
Es wird über eine schwere Kohlendioxyd-Azidose berichtet, die sich im Verlauf einer offenen Herzoperation mit kardiopulmonalem Bypass entwickelte. Die Kohlendioxyd-aufnahme wurde zurückgeführt auf eine über dem Operationsfeld befindliche Gaschicht, die versuchsweise zur Vermeidung einer Luftembolie aufgebracht worden war. Tierversuche bestätigten diese Quelle der Azidose. Bei Vergleich der Arbeitsweise des Beutel-oxygenators und der Melrose-Maschine fand sich kein Hinweis dafür, daß die Verwendung des Melrose-Oxygenators die schwere Azidose verhindert hätte.

ASSOCIATION OF ANAESTHETISTS OF GREAT BRITAIN AND IRELAND

A Scientific Meeting for Registrars will be held at Cardiff on April 22–24, 1965, and will be open to all junior anaesthetists up to and including those of senior registrar status. Residential accommodation has been arranged and there will be an informal dinner. However, as accommodation is limited priority will be given to Members of the Association.

Applications to attend the Meeting should be sent to the Honorary Secretary, Association of Anaesthetists, at The Royal College of Surgeons, Lincoln’s Inn Fields, London, W.C.2, by March 9, 1965.