STUDY OF THE OXYGENATION OF CARDIAC PATIENTS SUBMITTED TO EXTRACORPOREAL CIRCULATION

G. Barat, E. Dominguez de Villota, F. Avello and A. Ascorve

SUMMARY

Studies were made on eight patients submitted to extracorporeal circulation to correct valvular defects. Whilst breathing 100% oxygen, the alveolar/arterial oxygen tension difference and the Vd/Vt relationship were determined before the operations and during the first three days of the post-operative period. On 26 occasions, the arterio/venous oxygen content difference was measured and used to calculate the total intrapulmonary shunt. In all patients, the alveolar/arterial oxygen tension difference was increased above normal before operation. The postoperative values were always higher than the pre-operative ones. A significant mean increase was found on the second day. A slight but insignificant increase in the Vd/Vt relationship was found at each stage. In general, the values of the arterio/venous oxygen content difference were higher than the theoretical value of 5 vol.%. It is necessary to measure this difference in order to evaluate the true magnitude of the total intrapulmonary shunt despite the absence of clinical signs of low cardiac output.

One of the causes of postoperative hypoxaemia is the increase in the physiological or total intrapulmonary shunt. Two fundamental factors appear to contribute to this (Bergman, 1967; Diament and Palmer, 1967; Fordham, 1965; Geha et al., 1966):

1. The formation of pulmonary micro-atelectasis during anaesthesia, related to characteristics of controlled ventilation such as the tidal volume (Hedley-Whyte et al., 1964), end-tidal pressure etc. (2) The decrease in cardiac output following the operation itself (Prys-Roberts et al., 1958; Philbin et al., 1970).

The increase in total intrapulmonary shunt is not peculiar to heart surgery with extracorporeal circulation because it appears in all types of operations. In open-heart surgery, however, it takes on special importance (Eltringham et al., 1968; Hedley-Whyte et al., 1965; McClenahan et al., 1965) for the following reasons. Firstly, patients who require correction of cardiac defects, either acquired or congenital, always show some change in the ventilation/perfusion relationship as a consequence of the cardiac disease (Laver et al., 1970), which is reflected in the arterial blood oxygenation. Secondly, in the immediate postoperative period these patients readily develop low cardiac output states with subsequent decrease of arterial blood oxygen tension, especially when the cardiac output is less than 2.5 l./min.

The purpose of this study was to evaluate the total intrapulmonary shunt before and after surgery in cardiac patients submitted to extracorporeal circulation. The study was confined to the first three days following operation, without any attempt being made to analyze the consequences which these immediate changes could have, although it is known that they usually resolve themselves favourably if the patient survives the immediate postoperative period (McClenahan et al., 1965).

Changes in the ventilation/perfusion relationship were evaluated indirectly by determination of the alveolar/arterial oxygen tension difference. The total shunt was calculated taking the arterio/venous oxygen content difference as a fixed value (total theoretical shunt). At times this difference was calculated by the Van-Slyke and Neill technique; the shunt calculated in this way was named "total real shunt". Simultaneous determinations of the physiological dead space to tidal volume ratio were performed.

MATERIAL

Eight cardiac patients submitted to surgical correction of valve disease under cardiopulmonary bypass were studied. The general information about these

TABLE I. General information about the patients studied.

<table>
<thead>
<tr>
<th>Case</th>
<th>Sex</th>
<th>Age (Kg)</th>
<th>Diagnosis</th>
<th>Operation</th>
<th>Perfusion (min)</th>
<th>Intubation (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>44</td>
<td>AS,AR,MS,MR</td>
<td>Björk Ao, Carpentier M</td>
<td>75</td>
<td>32</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>43</td>
<td>AS,AR,MS</td>
<td>Björk Ao, M Valvulotomy</td>
<td>85</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>47</td>
<td>AR,AS</td>
<td>Starr-Edwards Ao</td>
<td>58</td>
<td>27</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>42</td>
<td>MS</td>
<td>M Valvulotomy</td>
<td>60</td>
<td>504</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>23</td>
<td>MS,MR,AR</td>
<td>Carpenter M</td>
<td>50</td>
<td>31</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>34</td>
<td>MS,AS</td>
<td>M Valvulotomy</td>
<td>30</td>
<td>27</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>39</td>
<td>MS</td>
<td>M Valvulotomy</td>
<td>35</td>
<td>28</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>14</td>
<td>AR</td>
<td>Björk Ao</td>
<td>70</td>
<td>25</td>
</tr>
</tbody>
</table>

| Mean value | 32 | 55.4 | 58 |


patients, including the diagnosis and operation performed, is shown in table I. In none of them was an intracardiac shunt observed during the procedure. In their previous history most of the patients had suffered episodes of cardiac insufficiency but during the study none showed clinical symptoms of cardiac insufficiency or low cardiac output. None had a history of chronic bronchitis; the vital capacity was more than 35 ml/kg bw, except in case 4 (27.8 ml/kg bw).

A median sternal incision was made routinely. Anaesthesia was induced with sodium thiopentone and suxamethonium, and maintained with nitrous oxide, fentanyl and droperidol. Muscle relaxation was obtained using tubocurarine or alcuronium. Pulmonary ventilation was controlled by means of the Bird Mark 8 + Mark 4 ventilator, adjusted to maintain arterial $P_{CO_2}$ values at about 30 mm Hg. During perfusion, the lungs were kept partially inflated with air to prevent shift of the mediastinum. The mean perfusion time was 58 min. Hypothermia and coronary perfusion were not used. Oxygen was administered after perfusion to obtain arterial oxygen tensions higher than 100 mm Hg.

During the postoperative period artificial ventilation was maintained for a minimum of 18 hours, by means of a Bennett, type PR2 ventilator with a cascade humidifier added; the temperature of the inspired gas was kept between 32 and 35°C. Tidal volumes between 10–15 ml/kg bw (Hedley-Whyte et al., 1964; Pontoppidan and Bushnell, 1967), and respiratory rates between 14 and 22 b.p.m. were used. Extubation was performed when the patient, breathing spontaneously and receiving 5–6 l./min of oxygen, maintained a $P_{O_2}$ higher than 70 mm Hg. The intubation time varied between 25 and 32 hours, with the exception of case 4, in which a tracheostomy was performed and controlled ventilation maintained for a prolonged period.

Postoperative complications were found only in cases 4 and 8. On the second day after the operation, case 4 presented complete atelectasis of the upper right lobe. Case 8 reached the unit with a haemothorax; after having done the study controls about 1,500 ml of blood was removed from the pleural cavity. All patients studied survived the immediate postoperative period.

**METHOD**

Twenty-four to forty-eight hours before operation, the preoperative control measurements ($P$) of the alveolar/arterial $P_{O_2}$ difference and $Vd/Vt$ ratio were made with the patient in the supine position. 100% oxygen was breathed spontaneously for at least 20 min by means of a perfectly-adjusted face-piece connected through a Wright respirometer to a meteorological balloon for collection of the expired gas. After 20 min of oxygen breathing, an arterial blood sample was taken by direct brachial arterial puncture and, at the same time, expired gas was collected during a 3 min period.

On the day of the operation, between 15 and 30 min after the patient reached the intensive care unit, ventilation with 100% oxygen was begun. After at least 20 min a sample of arterial blood was withdrawn from a radial artery or left atrial catheter, and expired gas collected into a meteorological balloon which was attached through a Wright Respirometer to the expiratory part of the Bennett ventilator.

On the first postoperative day, studies were also made during automatic ventilation. On the second and third days, they were made in the same manner as the preoperative ones, the arterial blood
samples being drawn from the radial or femoral artery. At the time of arterial sampling central venous blood was drawn on 26 occasions by means of a catheter placed in the right atrium, to determine the arterio/venous oxygen content difference.

The samples of blood were withdrawn under anaerobic conditions using glass syringes, paraffined and previously heparinized. Blood gas analysis was performed as soon as possible, and in all samples within 30 min. They were read in a Combi-Analyser (Betriebs-Anleitung. L. Eschweiler & Co., Kiel), the Po<sub>2</sub> electrode being of the Clarke type according to Lubbers and co-workers. The theoretical error of the unit for these readings is ±0.5% (manufacturer's figures). The Pe<sub>2</sub>, electrode was of stabilized glass according to Gleichman and co-workers, with a theoretical error of ±1% (manufacturer's figures). All blood gases were read at 38°C; no correction was made for the patient's temperature.

The partial pressure of carbon dioxide in expired air was also determined in the Combi-Analyser. Diffusion through the walls of the balloon was considered to be unimportant because all determinations were made within 30 min of sample collection.

The arterio-venous oxygen content difference was determined according to the technique of Van-Slyke and Neill (1924).

**CALCULATIONS**

The alveolar/arterial oxygen gradient (A-a) PO<sub>2</sub> diff. was calculated according to the formula (Bendixen et al., 1965):

\[
\text{(A-a) PO}_2 \text{ diff.} = \text{PAO}_2 - \text{PaO}_2
\]

The alveolar oxygen tension (PAO<sub>2</sub>) was assumed equal to:

\[
\text{PAO}_2 = (\text{Pb} - \text{P}_{H_2}O) - \text{Paco}_2
\]

In all calculations a water vapour pressure of 47 mm Hg was assumed.

**RESULTS**

The pre-operative and postoperative values for PAO<sub>2</sub>, Paco<sub>2</sub>, pH, standard bicarbonate (SB), alveolar/arterial O<sub>2</sub> gradient ((A-a)Po<sub>2</sub>,diff.), VD/VT, and theoretical total shunt (calculated assuming the arterio-venous difference in oxygen content to be 5 vol. % of oxygen), are shown in Table II*.

### Alveolar/arterial oxygen tension difference.

This was increased in all patients before operation. The mean difference was 215 mm Hg (range 160-269). 35 to 50 min after returning from the operating theatre, an increase in the difference was already apparent, the mean value being 272 mm Hg (range 163-375). On the following days, the mean values continued to increase: first day 323 mm Hg (range 183-500), second day 364 mm Hg (range 208-471); the difference between the pre-operative values and the values for the first and second day is statistically highly significant (P<0.001). However, on the third postoperative day there was an improvement and the mean value fell to 303 mm Hg (range 221-336; n=5).

The changes of the mean values are shown in

* Copies of complete data can be obtained from Dr G. Barat.

### Table II. Mean values with SEM of measured and derived data from eight patients undergoing correction of cardiac valvular defects with extracorporeal circulation.

<table>
<thead>
<tr>
<th></th>
<th>Pre-operative</th>
<th>Immediately postoperative</th>
<th>First postoperative day</th>
<th>Second postoperative day</th>
<th>Third postoperative day</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SEM</td>
<td>Mean</td>
<td>SEM</td>
<td>Mean</td>
</tr>
<tr>
<td>PAO&lt;sub&gt;2&lt;/sub&gt; (mm Hg)</td>
<td>618</td>
<td>2.188</td>
<td>619</td>
<td>2.603</td>
<td>618</td>
</tr>
<tr>
<td>Paco&lt;sub&gt;2&lt;/sub&gt; (mm Hg)</td>
<td>403</td>
<td>15.409</td>
<td>346</td>
<td>24.274</td>
<td>295</td>
</tr>
<tr>
<td>Paco&lt;sub&gt;2&lt;/sub&gt; (mm Hg)</td>
<td>38</td>
<td>0.693</td>
<td>35</td>
<td>1.861</td>
<td>35</td>
</tr>
<tr>
<td>pH</td>
<td>7.42</td>
<td>0.013</td>
<td>7.45</td>
<td>0.018</td>
<td>7.50</td>
</tr>
<tr>
<td>SB (m-equiv/L)</td>
<td>25.1</td>
<td>0.707</td>
<td>25.0</td>
<td>1.086</td>
<td>27.3</td>
</tr>
<tr>
<td>A-a Po&lt;sub&gt;2&lt;/sub&gt; diff. (mm Hg)</td>
<td>215</td>
<td>14.683</td>
<td>272</td>
<td>22.819</td>
<td>323</td>
</tr>
<tr>
<td>VD/VT</td>
<td>0.47</td>
<td>0.033</td>
<td>0.46</td>
<td>0.023</td>
<td>0.49</td>
</tr>
<tr>
<td>Shunt (%)</td>
<td>11.6</td>
<td>0.702</td>
<td>14.3</td>
<td>1.051</td>
<td>16.4</td>
</tr>
<tr>
<td>Hb (g/100 ml)</td>
<td>14.7</td>
<td>0.602</td>
<td>13.8</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
Vd/Vt

The pre-operative values show a slight increase above normal (mean 0.47). In the days following the operation the mean values changed little, remaining near the pre-operative values (table II, fig. 3). There were no statistically significant variations.

Theoretical and real intrapulmonary shunt.

The values given for the intrapulmonary or total shunt in table II and figure 4 were calculated assuming an arterio/venous oxygen content difference of 5 vol %. This total shunt has been termed theoretical shunt. The pre-operative values were raised above the normal range, the mean value being 11.6% of the cardiac output. The mean

The following figures show changes from pre-operative values (P) in eight patients undergoing correction of cardiac valvular defects with extracorporeal circulation. Values relating to day of operation at O.

Fig. 1. Changes in alveolar/arterial oxygen tension difference.

Values rose following the operation, being 14.3% immediately after operation and 16.4%, 18.3%, and 15.7% on the first, second and third postoperative days.

The increase immediately after operation is significant (P<0.05), the difference between the pre-operative values and the second day values being highly significant (P<0.001). However, the difference between the mean increases observed on successive days was not significant.

Realizing that the value of the arterio/venous oxygen content difference of the patients undergoing open heart surgery differs generally from the theoretical value, this difference was determined on 26 occasions, depending on the availability of laboratory facilities. Simultaneous determinations of the cardiac output and the oxygen consumption were not made. Using the measured values, the total shunt

Fig. 2. Changes in arterial oxygen tension.

Fig. 3. Changes in dead space/tidal volume rates.
TABLE III. Relationship between the values of the theoretical and the real total shunt percentage of the cardiac output.

<table>
<thead>
<tr>
<th>Case</th>
<th>Day</th>
<th>St</th>
<th>Cao1—Cvo2</th>
<th>Sr</th>
<th>Case</th>
<th>Day</th>
<th>St</th>
<th>Cao1—Cvo2</th>
<th>Sr</th>
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<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>18.86</td>
<td>5</td>
<td>18.86</td>
<td>5</td>
<td>0</td>
<td>14.10</td>
<td>12.51</td>
<td>6.16</td>
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<tr>
<td>1</td>
<td>1</td>
<td>18.45</td>
<td>4.80</td>
<td>19.07</td>
<td>5</td>
<td>1</td>
<td>11.08</td>
<td>10.46</td>
<td>5.62</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>22.60</td>
<td>12.01</td>
<td>10.83</td>
<td>5</td>
<td>2</td>
<td>20.34</td>
<td>6.86</td>
<td>15.69</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>18.12</td>
<td>5.56</td>
<td>16.60</td>
<td>6</td>
<td>0</td>
<td>15.32</td>
<td>9.35</td>
<td>8.82</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>17.40</td>
<td>6.73</td>
<td>13.91</td>
<td>6</td>
<td>1</td>
<td>12.09</td>
<td>7.22</td>
<td>8.70</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>18.98</td>
<td>11.76</td>
<td>9.06</td>
<td>6</td>
<td>2</td>
<td>20.54</td>
<td>4.39</td>
<td>22.74</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>14.88</td>
<td>7.41</td>
<td>10.55</td>
<td>7</td>
<td>0</td>
<td>11.27</td>
<td>4.09</td>
<td>13.44</td>
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<td>4</td>
<td>1</td>
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<td>4</td>
<td>2</td>
<td>11.42</td>
<td>10.30</td>
<td>5.89</td>
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<td>16.33</td>
<td>4.10</td>
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<tr>
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<td>24.13</td>
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<td>9.17</td>
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<tr>
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<td>5</td>
<td>20.10</td>
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<td>6</td>
<td>20.69</td>
<td>5.05</td>
<td>20.53</td>
<td>8</td>
<td>2</td>
<td>19.47</td>
<td>7.22</td>
<td>14.34</td>
</tr>
</tbody>
</table>

St = Theoretical total shunt, assuming Cao1—Cvo2 = 5 Vols. % O2.
Sr = Real total shunt, calculated on the arterial/venous O2 content difference.
Cao1—Cvo2 = Arterio/venous O2 content difference, calculated according to the Van-Slyke-Neill technique.
Total = 26 Determinations. Mean values: St = 16.81%; Sr = 12.86%; Cao1—Cvo2 = 7.59 vol % O2.
S.E. mean: St = 0.847; Sr = 0.969.

Significance: Difference between the mean of St and Sr; P < 0.0001.

Fig. 4. Changes in theoretical shunt.

Fig. 5. Relationship between theoretical shunt (assuming an arterio/venous oxygen content difference of 5 vols %) and real shunt, calculated using measured values.

The study of the real shunt, using data from patients 1, 4, 5, 6, 7 and 8, immediately after operation, and on the second postoperative day, shows that there was no significant change in the postoperative period, in contrast to the alveolar/arterial oxygen content difference and the theoretical shunt,
both of which were significantly increased on the second day. The mean values for the real shunt were 11.3% immediately after operation, 11.7% on the first day and 14.8% of the cardiac output on the second day; these values do not differ significantly from each other (t=0.14, 0.95, and 1.15 respectively).

**DISCUSSION**

As expected, the alveolar/arterial oxygen tension difference and the theoretical shunt were abnormally high in the preoperative stage as a consequence of pulmonary changes secondary to cardiac dysfunction (Laver, Hallowell and Goldblatt, 1970). The Vd/Vt ratio was found to be slightly elevated.

During the postoperative period, the Vd/Vt ratio also remained slightly but insignificantly elevated. Although it is known that decreases in cardiac output can reduce this value (Saunders, 1965), we found no significant relationship with variations in arterio/venous oxygen content difference.

Analysis of the postoperative changes in alveolar/arterial oxygen tension difference showed a significant increase with respect to the preoperative values, which is in agreement with the findings of several authors (Eltringham et al., 1968; Fordham, 1965; Geha et al., 1966; McClenahan et al., 1965). This increase is not confined to operations with extracorporeal circulation, as its existence has been demonstrated in relation to major operations on the upper abdomen (Diament and Palmer, 1967) and in heart surgery without extracorporeal circulation (Hedley-Whyte et al., 1965). It may be attributed to the existence of diffuse atelectatic areas in the lung parenchyma which cannot usually be detected radiologically. Several factors could contribute to the development of postoperative atelectasis in patients submitted to extracorporeal circulation such as lung changes following bypass (McClenahan et al., 1965; Nahas et al., 1965); low tidal volumes (Hedley-Whyte et al., 1964); absence of end-expiratory pressures during controlled ventilation (Ashbaugh, 1970); lack of sighs and shallow breathing associated with pain and sedation, and reduction of lung compliance following thoracotomy.

The maximum increase in the alveolar/arterial oxygen tension difference was observed on the second day following the operation, and this agrees with the results of other authors (McClenahan et al., 1965). On the third day a tendency towards normalization was observed, although this condition is not reached until after the eighth day (Eltringham et al., 1968; McClenahan et al., 1965). For this reason, oxygen therapy for several days following the operation has been recommended, even in patients progressing satisfactorily, and during more prolonged periods if any postoperative lung complication has arisen.

The importance that changes in the distribution of the inspired gas could have on the alveolar/arterial oxygen tension difference could not be evaluated because high concentrations of oxygen were employed. It is known, however, that in patients breathing air this can be an additional factor is the development of arterial hypoxaemia, especially in the first 24 hours following operation and in patients with mitral disease.

The fourth patient developed massive atelectasis of the right upper lobe, which was first apparent on the second day after the operation. The alveolar/
artrial oxygen tension difference had, however, already risen considerably on the preceding day (from 282 to 500 mm Hg). In contrast, case 8 reached the unit having a haemothorax containing about 1,500 ml blood. No significant changes were found in the study made before its evacuation, in spite of the radiological evidence of pulmonary compression. The alveolar/arterial oxygen tension difference in the patient was 163 mm Hg which was the lowest of any patient at this time and considerably less than the average (272 mm Hg). These two cases show that the alveolar/arterial oxygen tension difference is a valuable guide in the assessment of pulmonary function, and that there is often no correlation between the radiological findings and the magnitude of the alveolar/arterial oxygen tension difference and the intrapulmonary shunt.

Analysis of the values for the theoretical and real total shunt emphasizes the importance of measuring the true arterio/venous oxygen content difference, as a reflection of the cardiac output, in these patients in order to solve the shunt equation. In our patients the shunt values obtained using the theoretical arterio/venous oxygen content difference were significantly higher than those calculated using the real difference. The mean value of the real difference, obtained at different times during the postoperative period, was 7.59 vol %, this value differing from those of some authors (Boyd et al., 1959). In this study the samples of venous blood were not of true mixed venous blood, as they were not taken from the pulmonary artery. We feel, however, that the arterio/venous oxygen content difference measured on this central venous blood is more representative of the haemodynamic situation of the patient than a theoretical value of 5 vol %. We cannot know how much the values of this arterio/venous difference were influenced by ventilation with 100% oxygen, which is known to be associated with decrease in cardiac output (Daly and Bondurant, 1962), and by the hypoxaemia present on the first postoperative day, another factor which may diminish the cardiac output (Colgan and Mahoney, 1969) and on some occasions contribute to the hypoxaemia when the intrapulmonary shunt is greater than 5% of the cardiac output (Kelman et al., 1967).

The importance of knowing the arterio/venous oxygen content difference in order to assess the intrapulmonary shunt has been pointed out by several authors. Among them Colgan and Mahoney (1969) showed that changes in cardiac output in patients undergoing abdominal surgery can lead to inaccuracy in the calculation and interpretation of intrapulmonary shunting of blood. We found no correlation between the values of the real shunt and the alveolar/arterial oxygen tension difference. According to Bergman (1967) the magnitude of the alveolar/arterial oxygen content difference varies not only with the ratio of blood shunted to blood not shunted but also directly with the oxygen consumption and inversely with the cardiac output. The lack of correlation between the values of the real shunt and the alveolar/arterial oxygen content difference may be accounted for by variations both of the cardiac output and the oxygen consumption. We cannot assess the effect of oxygen consumption on the venous oxygen content and on the alveolar/arterial oxygen tension difference. Although it is known that shivering, pyrexia, restlessness, and struggling may cause large increases in oxygen consumption during the postoperative period (Bay, Nunn and Pryse-Roberts, 1968), we think that these factors did not contribute significantly to the rise in the alveolar/arterial oxygen content difference, taking account of the conditions in which the determinations were made.

The contribution of the cardiac output, diminished in most of the cases as the large values of arterio/venous oxygen content difference show, is more evident. A decrease in output will necessarily decrease in arterial oxygenation, if the true shunt and the oxygen consumption remain constant (Philbin et al., 1970). Kelman and associates (1957) have shown that appreciable reductions in arterial oxygen tension during and after anaesthesia may be caused largely by reductions in cardiac output and that the percentage of pulmonary venous admixture during anaesthesia may not be greatly increased when allowance is made for possible changes in cardiac output. Considering that the values of the real shunt do not differ from each other on the first days of the postoperative period, the rise observed in the alveolar/arterial oxygen tension difference, especially on the second day, is probably related to a diminished cardiac output. We think that in patients submitted to open heart surgery, the variations in the alveolar/arterial oxygen tension difference seen postoperatively may not be related to similar variations in the intrapulmonary shunt.

The clinical relevance of these results lies in the importance that changes in the cardiac output may have in the oxygenation of a patient with already raised intrapulmonary shunt. The haemodynamic situation is, therefore, a factor which should be
evaluated, together with the lung condition, in the management of postoperative hypoxaemia. The results indicate the extent to which the administration of oxygen is advisable in these patients during the immediate postoperative period, and emphasizes the necessity of considering the factors which favour the development of lung atelectasis and of taking appropriate steps to prevent it. Among these are the use of high tidal volumes and positive end-expiratory pressure during controlled ventilation, in addition to effective, careful, and systematic respiratory physiotherapy. Sometimes a high alveolar/arterial oxygen tension difference will return to normal levels only after the myocardial performance has improved. Prolonged oxygen therapy appears necessary for the maintenance of adequate oxygenation in those patients undergoing open heart surgery.

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REFERENCES

Daly, W. J., and Bondurant, S. (1962). Effects of oxygen breathing on the heart role, blood pressure, and cardiac index of normal resting man with reactive hyperemia and after atropine. J. clin. Invest., 41, 126.


ETUDE DE L'OXYGENATION DE PATIENTS CARDIAQUES SOUMIS A LA CIRCULATION EXTRACORPORELLE POUR CORRECTION DE DEFAUTS VASCULAIRES

SOMMAIRE

Des études ont eu lieu chez huit patients soumis à la circulation extracorporelle pour correction de défauts vasculaires. Sous respiration de 100 pourcent d'oxygène, on détermina la différence de pression oxygénique alvéolaire/arterielle et la relation VD/Vt avant les opérations et durant les trois premiers jours de la période post-opératoire. La différence du contenu oxygénique artériel et veineux a été mesurée à 26 reprises et utilisée pour calculer le shunt intrapulmonaire total. La différence d'oxygénation alvéolaire/arterielle dépassa la normale chez tous les patients avant l'opération. Les valeurs postopératoires furent toujours supérieures aux valeurs pré-opératoires. Une augmentation moyenne significative s'observa le second jour. On nota à chaque stade une augmentation légère mais non-significative de la relation VD/Vt. Les valeurs de la différence de contenu oxygénique artériel et veineux dépasseront en général la valeur théorique de 5 vol. pourcent, et il est nécessaire de mesurer cette différence pour évaluer la magnitude réelle du shunt intrapulmonaire total en dépit de l'absence de signes cliniques d'un débit cardiaque peu élevé.

Fueron efectuados estudios en ocho pacientes sometidos a circulación extracorpórea para corregir defectos valvulares. Mientras respiraban oxígeno al 100 por ciento, fueron determinadas la diferencia de tensión de oxígeno alveolar/arterial y la relación Vd/Vt antes de las operaciones y durante los tres primeros días del período posoperatorio. En 26 ocasiones fue medida la diferencia en el contenido de oxígeno arterial/venoso y utilizada para calcular el shunt intrapulmonar total. La diferencia de oxigenación alveolar/arterial estaba incrementada por encima del valor normal en todos los pacientes antes de la operación. Los valores posoperatorios fueron siempre mayores que los valores preoperatorios. En el segundo día fue encontrado un incremento medio significativo. En cada estadio fue hallado un incremento leve y no significativo en la relación Vd/Vt. En general, los valores de la diferencia del contenido de oxígeno arterial/venoso fueron mayores que el valor teórico de 5 vol. por ciento y es necesario medir esta diferencia para poder evaluar la verdadera magnitud del shunt intrapulmonar total a pesar de la ausencia de signos clínicos de gasto cardíaco bajo.