CARDIAC OUTPUT OF INDIAN MEN BY A NON-INVASIVE METHOD
THE INDIRECT FICK PRINCIPLE

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Summary: The cardiac output (Q) of seven young healthy Indians with common physical characteristics at rest and after a single bout of exercise of 600 kpm for 10 min on a bicycle ergometer was ascertained by the Indirect Fick Principle. The end tidal alveolar CO₂ pressure was obtained at the end of a normal expiration and PvCo₂ was obtained by the help of the exponential rise (Defares method) in CO₂ concentration during rebreathing from an initially low CO₂ mixture (3-4%). The standard CO₂ dissociation curve of oxygenated blood was used to find out the corresponding arterial and venous CO₂ content, assuming the Hb content of these individuals to be normal.

The mean value of the Cardiac-Output so obtained during rest is 4.21 liters/min when CO₂ rebreathing time does not exceed 10 secs, and 17.33 litres/min., 2 to 3 breaths after exercise, when rebreathing time did not exceed 5 to 7 secs. Repeat d studies and better training of the subjects will perhaps improve the resting values, while after exercise and during recovery our values are better reproducible.

Key words: cardiac output, CO₂ rebreathing, exercise, Pv Co₂, Ficks Principle

INTRODUCTION

There is much to be said in favour of non invasive techniques in the measurement of cardiac-output, where in analyses of cardiac and respiratory functions during exercise and recovery have been based on the sequence of processes transferring oxygen from the inspired air to the tissues and the reciprocal sequence of processes by which CO₂ passes from mixed venous blood to the expired air (5).

In the early studies the lungs were used as tonometers to equilibrate alveolar and pulmonary capillary blood gas tensions during breath holding. Douglas and Haldane (6) found reasonable estimates of cardiac-output by direct alveolar sampling for determination of the partial pressure of CO₂ in arterial blood (PaCO₂), the partial pressure of CO₂ in venous blood (PvCO₂) was estimated from the rise in the PvCO₂ during breath holding. Collier (3) was the first to obtain a CO₂ plateau indicating equilibrium during rebreathing from an initially high CO₂ mixture. An alternative to the plateau method was developed by Defares (4) based on an exponential rise of PCO₂ during rebreathing when an initially low CO₂ concentration was used. Good correlations have been found for the extrapolation method by various workers (7,11).
The present study is based on the Defas es technique wherein an exponential rise in \( PCO_2 \) is used to arrive at the \( PVCO_2 \) during rest and during submaximal exercise on the bicycle ergometer.

**MATERIALS AND METHODS**

The subjects chosen for this study belong to group of well nourished normal young healthy Indian volunteers of average age of 23.7 years. They were first familiarised with the rebreathing procedure and allowed to practice it twice before a 20 min rest. Then normal breathing frequency was matched with a metronome and they were instructed to follow the rhythm as evenly as possible during rest.

End tidal alveolar air samples were collected from the Collins low resistance valve and all gas analyses were done by a Beckman \( CO_2 \) analyser and linearised recorder. Ventilation during rest and exercise was recorded from a Kowan-Parkinson flowmeter.

Carbon dioxide rebreathing was done from a bag containing 2.5 litres of a mixture of 3\% \( CO_2 \) in oxygen, connected by a three way valve to the subject. Rebreathing was done in response to a quick count of 5 breaths in 10-12 seconds during rest and 5-7 seconds immediately after exercise.

The \( CO_2 \) percentage for these five breaths were plotted against time and the best fitting curve was subdivided into equal arbitrary time intervals. The \( PCO_2 \) was converted to the actual \( PCO_2 \) at the prevalent barometric pressure -47 mm Hg. The \( PVCO_2 \) was then extrapolated from these values.

The \( CO_2 \) content of mixed venous blood and \( CO_2 \) content of arterial blood is determined by substituting values of \( PaCO_2 \) and \( PVCO_2 \) on a standard \( CO_2 \) dissociation curve of oxygenated blood, assuming that Hb content is normal for these healthy subjects.

The calculation of the cardiac output is based on the Fick Principle.

\[
Q = \frac{\dot{V}CO_2}{CvCO_2 - CaCO_2}
\]

where \( Q \) = Cardiac output in litres/min.

\( VCO_2 \) = \( CO_2 \) output in ml/min.

\( CvCO_2 \) = ml of \( CO_2 \) /litre in mixed venous blood

\( CaCO_2 \) = ml of \( CO_2 \) /litre in arterial blood

This is a method based on the classical method of Defas, modified by Klausen (12). The exponential rise has been calculated by triple extrapolation by Campbell and Howell (2) and found to be satisfactory.

**RESULTS**

Table I describes the physical characteristics of the subjects. As is obvious they were deliberately chosen so that their physical characteristics were within a very narrow range.
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Table I: Physical characteristics of the subjects.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name</th>
<th>Age (yr)</th>
<th>Height (em)</th>
<th>Weight (kgms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R.K.</td>
<td>23</td>
<td>175</td>
<td>64</td>
</tr>
<tr>
<td>2</td>
<td>M.S.</td>
<td>23</td>
<td>163</td>
<td>52</td>
</tr>
<tr>
<td>3</td>
<td>R.S.</td>
<td>22</td>
<td>163</td>
<td>62</td>
</tr>
<tr>
<td>4</td>
<td>B.B.</td>
<td>27</td>
<td>185</td>
<td>63</td>
</tr>
<tr>
<td>5</td>
<td>R.C.</td>
<td>21</td>
<td>177</td>
<td>64</td>
</tr>
<tr>
<td>6</td>
<td>B.S.</td>
<td>21</td>
<td>169</td>
<td>57</td>
</tr>
<tr>
<td>7</td>
<td>M.S.</td>
<td>22</td>
<td>164</td>
<td>50</td>
</tr>
</tbody>
</table>

Mean ± Standard deviation 22.71±1.99 179.86±7.764 59.14±5.747

Table II indicates the results of the various physiological variables essential for obtaining the cardiac output and cardiac index, during rest, exercise and recovery phases of 15 min and 30 mins, following the exercise. It shows an increase in ventilation, VO₂ and VCO₂ from rest to exercise, which is proportional to the exercise load given, and a return back to near normal values, during the recovery phases. The PaCO₂ and the PvCO₂ as obtained by extrapolation show consistant changes during rest, exercise and recovery.

Table II: Mean values of cardio pulmonary functions during rest, exercise and recovery as obtained by the CO₂ rebreathing technique.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Rest</th>
<th>Exercise (600 K.P.M./min) 10 min duration</th>
<th>Recovery I (After 45 min exercise)</th>
<th>Recovery II (After 30 min exercise)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. VO₂ lit/min</td>
<td>0.307</td>
<td>1.420</td>
<td>0.441</td>
<td>0.355</td>
</tr>
<tr>
<td>2. VCO₂ lit/min</td>
<td>0.291</td>
<td>1.640</td>
<td>0.469</td>
<td>0.332</td>
</tr>
<tr>
<td>3. PaCO₂ mm Hg</td>
<td>37.32</td>
<td>44.18</td>
<td>38.08</td>
<td>37.50</td>
</tr>
<tr>
<td>4. PvCO₂ mm Hg</td>
<td>53.00</td>
<td>69.20</td>
<td>58.60</td>
<td>55.50</td>
</tr>
<tr>
<td>5. H.R. beats/min</td>
<td>64</td>
<td>138</td>
<td>75</td>
<td>73</td>
</tr>
<tr>
<td>6. Cardiac output Q, lit/min CO₂ method</td>
<td>4.21</td>
<td>17.33</td>
<td>5.68</td>
<td>4.34</td>
</tr>
<tr>
<td>7. Cardiac Indix</td>
<td>2.37</td>
<td>9.91</td>
<td>3.36</td>
<td>2.57</td>
</tr>
<tr>
<td>8. VE lit/min</td>
<td>8.14</td>
<td>30.06</td>
<td>11.53</td>
<td>8.93</td>
</tr>
</tbody>
</table>
The resting mean value of cardiac-output rose from 4.2 L/min to 17.33 L/min during exercise and attains the value of 5.68 L/min and 4.34 L/min 15 minutes and 30 mins following the exercise.

Fig. 1 is a typical example of how the PvCO₂ was extrapolated for one of the subjects, and the value of PvCO₂ during rest, exercise and the two recovery phase studies is shown.

![Fig. 1](image)

**Fig. 1:** Showing extrapolated PvCO₂ in the four phases of rest, exercise, recovery I and recovery II, of a single subject (R.K.) from values of end-tidal PVCO₂, from 5 breaths during rebreathing.

![Fig. 2](image)

**Fig. 2:** Showing a proportional increase in Oxygen consumption vs cardiac output with exercise, of the group. The interrupted lines (---) shows the range of values obtained and the dark line (-----) indicates the mean value.
Fig. 2 indicates the proportional increase in \( \text{VO}_2 \) as against cardiac output in all the four phases of the total group of subjects. At rest the average \( \text{VO}_2 \) is 0.37 ± 0.13, after exercise \( \text{VO}_2 = 1.425 \pm 0.13 \), after recovery I, \( \text{VO}_2 = 0.414 \pm 0.09 \) and after recovery II, \( \text{VO}_2 = 0.355 \pm 0.082 \).

**DISCUSSION**

This method is based on the following assumptions:

1. No significant \( \text{CO}_2 \) pressure gradient exists between the end tidal alveolar and arterial blood.
2. The rate of blood flow during rebreathing is constant.
3. Recirculation of blood during rebreathing is negligible.

Differences in the PaCo\(_2\), the (a-A) Co\(_2\) gradient have been reported by various workers (14, 15). These differences in absolute values were attributed to the non-uniformity of distribution of blood and gas throughout the lungs especially due to postural changes. Contrarily Larsen and Severinghaus (13) found little non-uniformity due to postural changes.

Rode and Shephard (17) suggest that even if gas distribution is poor, gas derived from poorly ventilated alveoli is necessarily closer to mixed venous composition. And then again, the effect of ventilation perfusion inequality on blood gas tensions has been found to be much less during exercise, than at rest, and only at very heavy loads, wherein diffusion may limit oxygen transport (10,11).

However, computations of ventilation perfusion formulations of Rahn and Farhi (16) have helped in the optimization of the pulmonary gas exchanger. It has been shown mathematically that the independent variables are \( \dot{V}, Q \) and the initial compositions, while the dependent variables (or outputs) are \( \dot{V}_{O_2}, \dot{V}_{CO_2}, \dot{V}_N_2 \) and the final alveolar tensions. These tensions have been shown to depend only on the ratio of ventilation to perfusion and not on the absolute values, of either (8).

The \( \text{PvCO}_2 \) by extrapolation is slightly high especially during rest due to technical factors in the construction of the line and the difficulty in deciding what constitutes end-tidal, PCO\(_2\). However, repeated experiments at regular rates of respiration and regular lengths of rebreathing time in quick succession at rest, have given more accurate results.

The use of the standard \( \text{CO}_2 \) dissociation curve of oxygenated blood can perhaps give rise to an error since the curve is affected by changes in pH, temperature etc. Machardy (14), has shown that the relationship between the differences in pressures and concentrations in arterial and venous blood is only slightly influenced by considerable differences between the position of individual dissociation curves and plasma pH. The slope of the curve in this position will not change significantly if H\(_b\) content of the subjects used is within normal limits.
The rebreathing technique can be validated by repeated experiments and newer concepts depending upon mathematical models for optimisation of the pulmonary gas exchanger, to eventually establish the reproducibility and accuracy of the technique. The training of the subject for a consistent and even exponential rise in $P_{VCO_2}$ during rest and during exercise is essential.

With the advent of rapid $CO_2$ analyses and modifications in the technique of obtaining $P_{VCO_2}$, the indirect Fick-principle is perhaps the best most convenient method of calculating cardiac output.

Evaluations of these rebreathing methods for obtaining $P_{VCO_2}$ have been compared with direct measurements on pulmonary arterial blood, by the more adventurous methods of catheterisation, dye-dilution and by sophisticated radioisotope techniques, wherein transient measurement will give fleeting glimpses of a more continuous process, which may be very precise and accurate but difficult to time and phase.

REFERENCES