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 CO_2 pressure was obtained at the end of a normal expiration and $PvCO_2$ was obtained by the help of the exponential rise (Defares method) in CO_2 concentration during rebreathing from an initially low CO_2 in O_2 mixture (3-4%). The standard CO_2 dissociation curve of oxygenated blood was used to find out the corresponding arterial and venous CO_2 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 CO_2 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. Repeated 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 out-put CO_2 rebreathing   exercise $PvCO_2$ 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 transfering oxygen from the inspired air to the tissues and the reciprocal sequence of processes by which CO_2 passes from mixed venous blood to the expired air (5).

In the early studies the lungs were used as tonometers to aquilibrate 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 CO_2 in arterial blood ($PaCO_2$), the partial pressure of CO_2 in venous blood ($PvCO_2$) was estimated from the rise in the $PvCO_2$ during breath holding. Collier (3) was the first to obtain a CO_2 plateau indicating equilibrium during rebreathing from an initially high CO_2 mixture. An alternative to the plateau method was developed by Defares (4) based on an exponential rise of PCO_2 during rebreathing when an initially low CO_2 concentration was used. Good correlations have been found for the extrapolation method by various workers (7,11).

The present study is based on the Defa 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 familiarished 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 rythum 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.

$$\dot{Q} = \frac{\dot{V}Co_2}{CvCo_2 - CaCo_2}$$

where $\dot{Q}$ = 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 Def .res, 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 choosen so that their physical characteristics were within a very narrow range.

TABLE I: Physical characteristics of the subjects.

S.No.	Name	Age (ys)	Height (cms)	Weight (kgms)
1	R.K.	23	175	64
2	M.S.	23	163	52
3	R.S.	22	163	62
4	B.B.	27	185	65
5	R.C.	21	177	64
6	B.S.	21	169	57
7	M.S.	22	164	50
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, Vo_2 and VCo_2 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 $PaCo_2$ and the $PvCo_2$ 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 Co_2 rebreathing technique.

Parameters	Rest	Exercise (600 K.P.M./ min) 10 min duration)	Recovery I (After 45 min exercise)	Recovery II (After 30 min exercise)
1. Vo_2 lit/min	0.307	1.420	0.441	0.355
2. VCo_2 lit/min	0.291	1.640	0.469	0.332
3. $PalCo_2$ mm Hg	37.32	44.18	38.08	37.50
4. $PvCo_2$ mm Hg	53.00	69.20	58.60	55.50
5. H.R. beats/min	64	138	75	73
6. Cardiac output Q lit/min Co_2 method	4.21	17.33	5.68	4.34
7. Cardiac Indix	2.37	9.91	3.36	2.57
8. VE lit/min	8.14	30.06	11.53	8.93

The resting mean value of cardiac-output rose from 4.2L 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 $PvCo_2$ was extrapolated for one of the subjects, and the value of $PvCo_2$ during rest, exercise and the two recovery phase studies is shown.
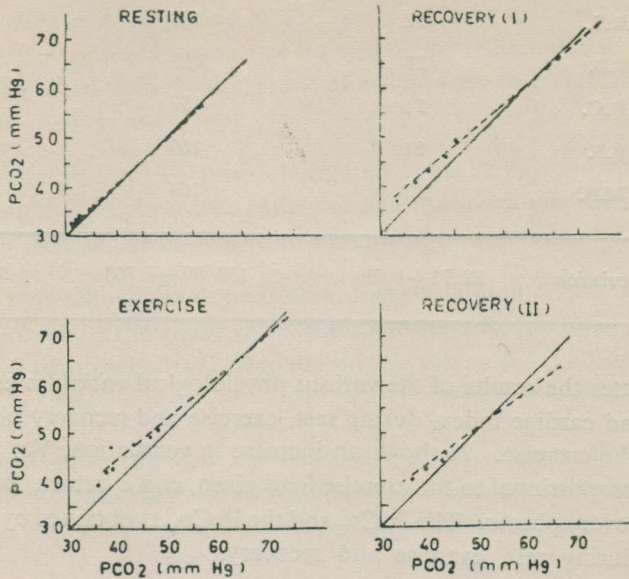

Fig. 1: Showing extrapolated Pv Co_2 in the four phases of rest, exercise, recovery I and recovery II, of a single subject (R.K.) from values of end-tidal $PVCo_2$, from 5 breaths during rebreathing.
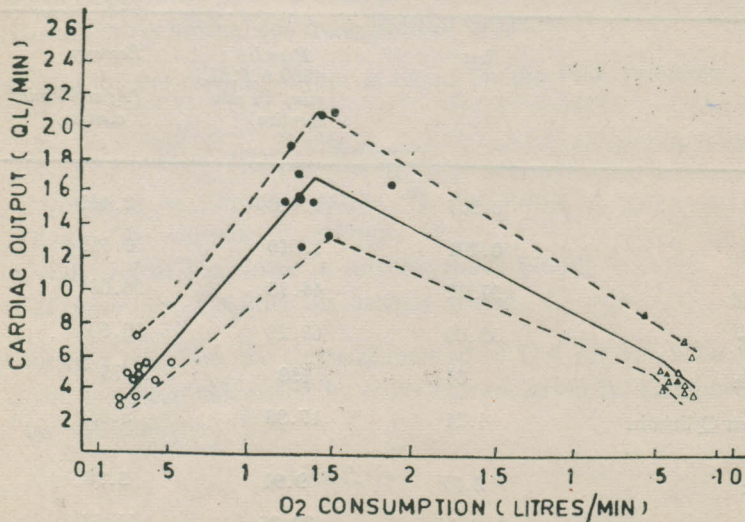

Fig. 2: Showing a proportional increase in Oxygen consumption vs cardiac output with exercise, of the group. The interrupted lines(- - -) shows the range of values obtained and the dark line (————) indicates the mean value.

Fig. 2 indicates the proportional increase in Vo_2 as against cardiac output in all the four phases of the total group of subjects. At rest the average Vo_2 is .037 $\pm$.13, after exercise $Vo_2 =$ 1.425 $\pm$0.13, after recovery 1, Vo_2=.414$\pm$.09 and after recovery II, Vo_2=.355$\pm$.082.

DISCUSSION

This method is based on the following assumptions:

1. No significant 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 rebreating is negligible.

Differences in the $PaCo$, the $(a\text{-}A)\,Co_2$ 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 distributon is poor, gas derived from poorly ventilated alvoeli 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 $\dot{V}$, $\dot{Q}$ 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 $PvCo_2$ 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 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 Hb 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 consistant and even exponential rise in $PvCo_2$ during rest and during exercise is eseential.

With the advent of rapid Co_2 analyses and modifications in the technique of obtaining $PvCo_2$, the indirect Fick-principle is perhaps the best most convenient method of calculating cardiac output.

Evaluations of these rebreathing methods for obtaining $PvCo_2$ 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.

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