OXYGEN UPTAKE DETERMINATION DURING SEVERE EXERCISE IN A HYPERBARIC ENVIRONMENT

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ABSTRACT

A method is described which enables accurate measurement of oxygen uptake ($\dot{V}O_2$) in exercising subjects breathing 95% oxygen by open circuit respirometry. A mixture of 5% helium in oxygen is inspired until steady-state equilibrium has occurred (60 min.). During subsequent work tasks the helium concentrations of the inspired and expired gas mixture are measured on a helium analyser and substituted for F_IN_2 and F_EN_2 in the appropriate gas exchange equations. Contamination of the collected respired gas samples with atmospheric nitrogen is thus measurable and appropriate corrections can be made.

INTRODUCTION

The Douglas bag open circuit method is inaccurate for inspired O_2 concentrations greater than 50% (5) thus $\dot{V}O_2$ measurement in exercising subjects breathing high O_2 concentration has been a difficult task. To date there are no published exercise $\dot{V}O_2$ measures in O_2 at high pressure (OHP); in a few cases only, $\dot{V}O_2$ during exercise in O_2 has been estimated by assuming reasonable values of the respiratory exchange ratios R (7). In general two practical methods for measuring $\dot{V}O_2$ exist: closed circuit spirometry and open-circuit techniques.

Closed Circuit Respirometry:

Closed circuit spirometry presents problems in situations where exercise is undertaken. Subjects exercising at very high work rates (1800 kpm/min) may demonstrate a minute ventilation ($\dot{V}_E$) exceeding 100 l/min. In this case resistance sites such as soda lime canisters cause the energy of breathing at high work rates to become generally unacceptable. In addition CO_2 may surpass the absorber capacity and temperature fluctuation become too great.

Open Circuit Respiratory:

The open-circuit technique is one in which the expired gas volume is measured and the gas analyzed. This procedure is based upon the fact that there is no net exchange of N_2 across the lungs. The volume of inspired gas may be calculated and the usual substitutions give:

$$\dot{V}O_2 = \dot{V}_E \; \frac{F_{IO_2} \cdot F_{EN_2}}{F_{IN_2}} - F_E\,O_2 \qquad \text{Equation 1.}$$

This method works well in exercise provided that a steady state of the inert gas in respired gas is achieved. A technique using N_2 as the constant inspired inert gas cannot be used when almost 100% O_2 is breathed at normal pressure. Nor can it be applied when breathing high O_2 concentrations under hyperbaric pressure, until sufficient time has elapsed to render inspired and expired N_2 concentration equilibrated. Analysed respired gas is liable, in both cases, to undeterminable contamination from atmospheric N_2. The open-circuit technique, however, could be applied if a small known percentage of inert gas, different from N_2 were added to O_2 and the mixture breathed for a period of time sufficient to allow equilibration of inspired and expired inert gas tensions. This would allow calculation of $\dot{V}O_2$, $\dot{V}CO_2$ and R as previously for normal air, under conditions approaching 100% O_2 breathing.

Helium-Oxygen Gas Breathing Mixtures

He has been selected as the inert gas to be added to O_2 for several reasons. The first was that contamination of aliquot samples for analysis would likely be caused by air and He could be readily distinguished from air N_2. Appropriate corrections could then be made. Another reason for the selection of He is its superior coefficients of absorption and diffusion, steady state equilibration of the body tissues is reached in 1/2 to 1/3 of the time required for N_2. Also the He capacity of saturated body tissues is only 40% of the N_2 content when equal partial pressures are breathed (6). Four main physiological properties of He must be considered in applying the method. First He is an inert gas and is not known to enter into any metabolic reactions. Secondly, like N_2 and the aliphatic anaesthetics, He fits the Meyer-Overton hypothesis (6) which relates the narcotizing effects of a gas to the magnitude of the oil-water partition coefficient. Thus, a gas which is grossly more soluble in oil than in water would possess a potent narcotizing action. He, having an oil-water partition coefficient of only 1.7:1 has a negligible narcotizing effect except at massive partial pressures (4). 5% He at 1 ata, 2 ata or 3 ata does not approach this level. Thirdly, He is less dense than N_2 and thereby reduces airway resistance and the work of breathing when relatively high concentrations are used (1). The respiratory resistance of air or He-O_2 is proportional to the square roots of the specific gravities of these gas mixtures. As the specific gravity of 95% O_2 - 5% He is virtually unity (1.057) there should be negligible change in work of breathing as compared to air. Lastly, although He is highly thermoconductive which could, for example, effect those O_2 and CO_2 analyzers with a thermoconductive principle, in (3) small concentrations this effect is not detectable.

Equilibration of He With Body Tissue

By accepting 5% He - 95% O_2 as a suitable inspiratory gas for use in the study of VO_2 in exercise under high inspired O_2 tensions, it was necessary to calculate a suitable equilibration period before a steady state (F_I He = F_EHe) can be assumed. The He equilibration curves (3), show that uptake or elimination of the gas follows an exponential curve (equation: $Y = Q\,(1-e^{-kt})$. In a typical equilibration curve, Behnke found that 77% of equilibration had occurred by 60 min., in 90 min. additional equilibration was only 8.4%. Therefore, the curve is relatively flat at the end of 1 hr. Furthermore, it has been found that whereas exercise increased He equilibration 60% during the initial period the overall effect over 30 min. was not appreciable (2).

METHOD

Adequacy of Helium Equilibration

The reliability of 60 min. body tissue He equilibration at rest was assessed. Secondly the measure ment of $\dot{V}O_2$ during exercise at 1 ata and 2 ata in O_2 was compared to air breathing. He equilibration was tested in the same subject 4 times after having inspired 4.72% He (balance O_2) for 60 min. sitting quietly. The gas was administered at a flow rate of 15 l/min from a 200 liter meteorological balloon through a Collins non-kinkable hose and non-returning mouthpiece. The gas administered was vaporized through 2 Bird In-line nebulizers. Expired gas passed to a 5 liter gas-mixing chamber, from which expired gas samples were with drawn, for O_2 and CO_2 analysis and then exhausted through a Parkinson-Cowan gas meter. Gas samples for He analysis were collected directly from the inspired and expired lines in 5 liter bags. Begining 60 min. after the start of He-O_2 inhalation, expired samples were obtained every 3 min. for a 15 min. period. The measurements were made at both 1 ata and 2 ata. Analysis was made of all samples. He was analysed using a Cambridge Helium Indicator after CO_2 absorption in soda lime. O_2 and CO_2 content in gas samples was analysed using Beckman O_2 and CO_2 analysers.

$\dot{V}O_2$ Determination Breathing He - O_2 Mixtures During Exercise

The same procedures were followed as outlined above except that after the 60 min. He equilibration period, the subject quickly changed from a plastic bag to a breathing valve and completed a prescribed worl tasks of 600, 1200 and 1800 Kg/min (100 rpm) for varying periods up to 6 min. Both syringe and bag samples were taken and analysed for O_2, CO_2, and He respectively. Samples were collected during the last min. of a 5 min. warm up and during each min. of the exercise.

RESULTS

Table 1 shows the mean expiratory He concentration and the range of variation for the equilibration experiment. It is probable that the expired He fractions are less than inspired He fractions due to dilution of expired gas by residual outgasing of N_2. Stable levels of He fractions in inspired and expired gas were attained sufficient to allow substitution in Equation 1. Table 2 shows values for $\dot{V}_E$, $\dot{V}O_2$, $\dot{V}CO_2$ and R during exercise at 1800 Kpm/min at 1 ata air, 1 ata O_2, 2 ata air and 2 ata O_2 using the method. These are reasonable values for respiratory gas variables. Expected R values for severe exercise are in the range of .95 to 1.15 and as may be seen experimentally obtained values for severe work in this experiment are within this range.

CONCLUSIONS

$\dot{V}O_2$, $\dot{V}CO_2$ and R can be measured using the open circuit method of gas measurement and analysis, during severe exercise while breathing O_2 concentrations exceeding 95%. If approximately 4-5% He is inspired with the O_2 and time is allowed for adequate He equilibration then the He fractions may then be substituted for the usual N_2 fractions in calculation of $\dot{V}O_2$. Theoretically and in practice, it was found that a 60 min. period of gas equilibration was sufficient to reach a steady-state of inspired expired He and N_2 concentration. This period of time is more dependent upon N_2 out gassing than upon He equilibration because of the solubility and diffusing characteristics of the former gas.

TABLE 1. Equilibration of inspiratory and expiratory He concentrations after breathing 4.72% He for one hour.

		F_EHe				
	F_IHe	60 min	65 min	69 min	71 min	75 min
Mean He %	4.72%	4.71	4.70	4.71	4.69	4.68
Range	0	4.67-4.72	4.68-4.72	4.68-4.72	4.69-4.47	4.57-4.72

TABLE 2. Respiratory gas exchange variables for exercise at 1800 Kpm/min. at 1 and 2 ata (air) and 1 and 2 ata (100% O_2)

Condition	Time (min)	$\dot{V}_{EATPS}$ l/min	$\dot{V}CO_2$ l/min	$\dot{V}O_2$ l/min	R
1 ata (air)	2	121.0	3.51	3.66	0.96
	4	134.0	4.00	4.04	0.99
	6	141.3	4.28	4.16	1.02
1 ata (100% O_2)	2	99.2	3.46	3.47	1.00
	4	126.8	4.05	4.02	1.00
	6	134.2	4.14	4.13	1.00
2 ata (air)	2	85.0	3.41	3.41	1.00
	4	112.6	4.43	4.06	1.09
	6	122.6	4.49	4.28	1.05
2 ata (100% O_2)	2	85.3	3.41	3.39	1.01
	4	99.3	4.01	4.00	1.00
	6	110.8	4.47	4.51	0.99

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