

Effects of Progressively Increasing Work Rate Exercise on Body Substrate Utilisation

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During steady-state of moderate intensity exercise tests, respiratory quotient (RQ) provides an accurate reflection of body substrate utilisation. The body and muscle RQ can be estimated from the increase of CO₂ output relative to the increase in O₂ uptake. In the present study, we examined the effects of progressively increasing work rate on the substrate utilisation of body and exercising muscles.

Eighteen male subjects performed an incremental exercise test. The work protocol started with 20 W cycling at 60 rpm for four minutes as a warm-up period then it was increased 15 W/min by a work rate controller until the limit of tolerance. Ventilatory and pulmonary gas exchange variables were measured using a turbine volume transducer and mass spectrometry and estimated breath-by-breath.

During warm-up period, total body RQ was 0.82±0.05, reflecting both carbohydrate and fat oxidation. With increasing work rate RQ increased and at the anaerobic threshold, it reached a value of 0.96±0.04, reflecting predominantly (85%) carbohydrate utilisation. At the respiratory compensation point, RQ increased to 1.29±0.19 due to the excess CO₂ production from the HCO₃⁻ buffering of lactic acidosis. At maximal exercise performance RQ was found to be 1.75±0.42 reflecting CO₂ from aerobic and anaerobic metabolism and also CO₂ from hyperventilation.

Consequently, substrate utilisation for the total body derives proportionally more from carbohydrate than from lipid stores during exercise as work rate increases..

Key words: Exercise test, respiratory quotient, anaerobic threshold

Introduction

During exercise, arterial blood lactate concentration increases above its resting level when a specific intensity of work rate is reached. This point is called as the anaerobic threshold (an) (1) and used as an important parameter to determine aerobic to anaerobic metabolic transitions in response to the muscular exercise performance.

The ratio of CO₂ output (VCO₂) to O₂ uptake (VO₂) as measured at the mouth (i.e. respiratory exchange ratio, R=VCO₂/VO₂) reflects CO₂ production (QCO₂) to O₂ consumption (QO₂) ratio of the exercising muscle (i.e. respiratory quotients RQ=ΔVCO₂/ΔVO₂), when there is steady-state in mild to moderate aerobic exercise, (i.e. work rate below the an) (2). During constant load heavy exercise (i.e. work rate performed above the anaerobic threshold), R becomes differ than RQ due to anaerobic metabolism and lactate production.

However, there is no sufficient data to explain the relation between the progressively increasing work rate and change in body substrate utilisation.

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In the present study, we aimed to examine the effects of progressively increasing work rate exercise test which contains aerobic, aerobic-anaerobic and anaerobic metabolism on the metabolic changes of the exercising muscles and also determine the body substrate utilisation non-invasively from the ratio of $\Delta VCO_2/\Delta VO_2$.

Materials and Methods

Sixteen untrained healthy male subjects (Table 1) were participated after giving written informed consents which were approved by the local ethics committee.

Table 1. Mean±SD values of physical characteristics of the subjects.

	Age yr	Weight kg	Height cm	WRmax (W)	VO ₂ max (l/dk)	an (l/dk)	% an
Mean	23.6	73.6	177	246	3.11	1.76	56.6
± SD	4.3	9.3	7.2	39	0.54	0.31	0.49

Each subject performed an incremental exercise test to the limit of tolerance on an electromagnetically braked cycle ergometer (Lode, Excalibur).

The work protocol was started for a period of four minutes cycling at 20 watts (60 rpm) as a warm-up period. Then, the work rate was increased by 15 watts each minute by a work rate controller and continued to the subjects limit of tolerance as shown by Whipp et al (3).

During exercise tests, the subjects were breathed through mouthpiece attached to a low resistance (1.5 cmH₂O at 3 L/sec) and low dead space (less than 90 ml) turbine volume transducer (Alpha Technology) to measure inspired and expired volumes. Respired air gas concentrations were measured by a quadrupole mass spectrometer (CaSE, QP9000) for continuous monitoring of O₂, CO₂ and N₂. The calibration and validation of the system have been performed prior to each study as described by Huszczuk et al (4). Ventilatory and pulmonary gas exchange variables were estimated using breath-by-breath Beaver algorithm (5). Heart rate was derived beat by beat from the R-R interval of a standard six-lead ECG (Quinton 5000) and monitored continuously throughout the all test.

During incremental exercise test, RQ was estimated for the periods of: a) warm-up to an reflecting aerobic metabolism b) an to respiratory compensation point (RCP), reflecting onset of

anaerobic metabolism c) RCP to maximal exercise performance, reflecting mainly anaerobic metabolism.

During incremental exercise test, RQ was determined and compared with the respiratory exchange ratio (R).

Aerobic to anaerobic transition which is also called as an an was estimated non-invasively (Figure 1) using V-slope method (6) which depends upon the increase in CO₂ output due to the excess CO₂ production from bicarbonate buffering of metabolic (chiefly lactic) acidosis compared to the O₂ uptake during incremental exercise test (7). RCP was estimated non-invasively where the partial pressure of end-tidal CO₂ (P_{ET} CO₂) decreases systematically (8) (Figure 1).

A paired-t test was used to evaluate the statistical significance of differences between values. Differences were considered significant at p<0.05.

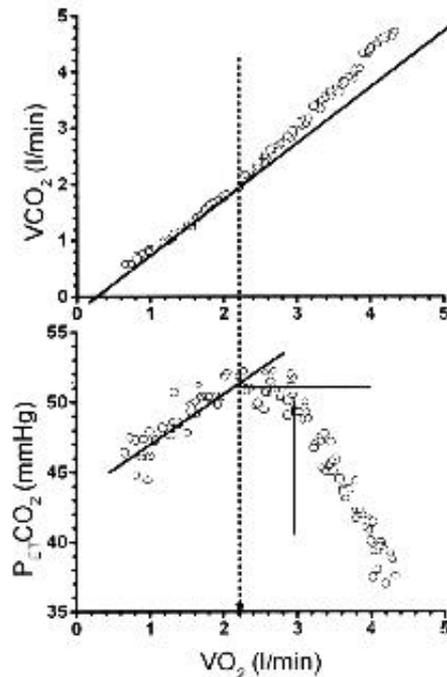


Figure 1. Representative responses in a typical subject of CO₂ output (VCO₂) and partial pressure of end-tidal CO₂ (P_{ET} CO₂)

Results

The mean (±SD) responses for the maximal exercise performance (WRmax) and VO₂ at maximal exercise (VO₂max) were 246±39 W and 3.11±0.54 l/min respectively (Table 1).

Estimated an from the plot of VCO₂ as a function of VO₂ during incremental exercise (i.e. V-slope) is illustrated in Figure 1. The aerobic to anaerobic

metabolic transition occurred at 56.6% of VO_2max and VO_2 at an was 1.76 ± 0.31 l/min (Table 1).

The mean (\pm SD) responses of VCO_2 and VO_2 at 20 W cycling, an, RCP and WRmax were also plotted (Figure 2). Beyond the an, the linearity between VCO_2 and VO_2 has been changed and VCO_2 increased out of proportion to the VO_2 .

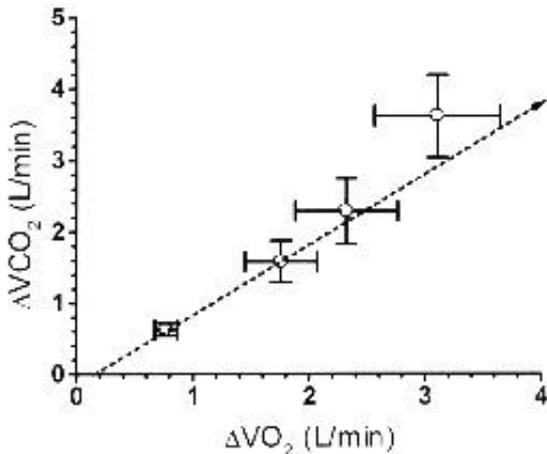


Figure 2. Mean (\pm SD) values of CO_2 output (VCO_2) as a function of O_2 uptake (VO_2)

The relationships between RQ and R in response to the progressively increasing work rate exercise test were shown in Figure 3. During warm-up period, total body RQ was equal to R and they were found to be 0.82 ± 0.05 , reflecting both carbohydrate and fat oxidation (Table 2). When the work rate increased, RQ increased more rapidly in relative to the R. At the an, RQ and R were 0.96 ± 0.04 and 0.90 ± 0.04 , respectively (Table 2). Beyond an, RQ increased to 1.29 ± 0.19 (at RCP) which is considerable over the value of 1.00 which reflects purely carbohydrate utilisation (Table 2, Figure 3) while R is still around 1.00 (0.98 ± 0.03).

At maximal exercise performance, RQ and R were found to be 1.75 ± 0.42 and 1.16 ± 0.08 (Table 2).

Table 2. Mean \pm SD values of physical characteristics of the subjects.

	RQ	R
20W	0.85 ± 0.05	0.85 ± 0.05
Oan	0.96 ± 0.05	0.90 ± 0.04
RCP	1.29 ± 0.09	$0.98 \pm 0.03^*$
Wmax	1.75 ± 0.26	$1.16 \pm 0.08^*$

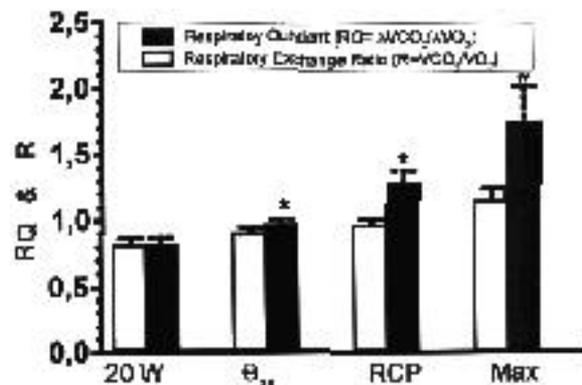


Figure 3. Bar graph showing mean (\pm SD) values of respiratory quotient (RQ, $\Delta\text{VCO}_2/\Delta\text{VO}_2$)

Discussion

The result of this study shows that VCO_2/VO_2 (i.e. metabolic RQ) can also be used to estimate substrate utilisation and metabolic changes non-invasively during progressively increasing work rate exercise.

During an incremental exercise test, the transition from aerobic to anaerobic metabolism occurred at 56% of VO_2max which is accepted in normal range for untrained subjects (9).

In response to the progressively increasing work rate exercise tests, for the period of work rate below the an, CO_2 comes from oxidative metabolism which consume O_2 for energy production (10). However, during work rate above the an, VCO_2 increases due to the lactic acidosis (2, 11).

Following warm-up period, with increasing work rate, increase in RQ from 0.85 ± 0.05 (warm-up period) to 0.96 ± 0.05 (at an), reflects the shift from mix substrate utilisation (both glucose and fatty acids) to mainly carbohydrate utilisation. This can be related to O_2 utilisation which is more efficient in carbohydrate utilisation (2). However, during constant load exercise test, fat oxidation increases when the work rate increased from low to moderate intensity (12).

Substrate utilisation of the exercising muscle can be affected by the fitness of the subjects and trained subjects can utilise more fatty acids than unfit one for a given level of work rate (13). Furthermore, substrate availability is also important factor on metabolism and exercising performance (14). It has previously been shown that glycogen availability in exercising muscle also has an effect on RQ (15).

Above an, RQ increased systematically above 1.00 (Figure 3), reflecting CO₂ production from anaerobic and also aerobic metabolism. This increase in CO₂ production results a non-linear increase in VCO₂ compared to the VO₂ (Figure 2).

It has previously been demonstrated that during exercise, increase in blood lactate concentration inhibits lipolysis and thus force obligatory carbohydrate utilisation (16).

When the work rate incremented further, subjects were hyperventilating which resulted decrease in P_{ET}CO₂ (Figure 1). In this part of the incremental exercise test, RQ increased due to the additional

CO₂ coming from hyperventilation in addition to the aerobic and anaerobic metabolism (17).

It has been reported that during short duration of constant load moderate intensity exercise, whole body R does not accurately reflects muscle substrate utilisation and R systematically lower than RQ (18). It is also important to emphasise that RQ was systematically higher than R during incremental ramp exercise, except the initial warm-up period.

Consequently, substrate utilisation for the total body derives proportionally more from carbohydrate than from lipid stores during exercise as work rate increases.

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