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Effects of Increased Respiratory Resistance on Maximal O_2 Uptake and Anaerobic Threshold during Incremental Exercise Tests

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Abstract: This study was undertaken to assess whether maximal O_2 uptake (VO_2max) can be used as an index of measuring aerobic capacity under the condition of increased respiratory resistance. Seven male subjects performed two incremental exercise tests on a cycle ergometer on different days: one control (C) and one breathing through an 8 mm bore diameter respiratory resistance (R). Ventilatory and gas exchange responses were measured with a turbine volume transducer and mass spectrometry, and processed breath-by-breath. VO_2max was measured and anaerobic threshold (AT) was estimated non-invasively using the V-slope method. Maximal exercise performance was reduced significantly (by paired t-test, $P<0.05$) in the resistance study (233±14 W) compared to the control (260±29 W). The plateau in VO_2 is not a consistent feature of incremental exercise tests even in the control study at the subjects' maximum effort. VO_2 at maximal exercise performance was also reduced significantly from 3.25±0.40 l/min (C) to 2.83±0.20 l/min (R). However, there were no significant differences between AT for both tests: 1.80±0.28 l/min (C) and 1.81±0.28 l/min (R). These results establish that AT actually reflects aerobic capacity. Therefore, AT should be determined systematically in addition to VO_2max during maximal exercise tests to better evaluate physical fitness.

Key Words: O_2 uptake, Anaerobic threshold, Exercise test

Introduction

Cardiopulmonary exercise tests, also called stress tests, have been widely used in clinical medicine and sports science as valuable measurement tools for the assessment of subjects' cardiopulmonary endurance and the determination of aerobic capacity (1-4).

Measurements of maximal O_2 uptake (VO_2max), which is defined as reaching a plateau of VO_2 despite further increases in work rate (5) and which reflects the upper limit of body O_2 uptake (VO_2) and utilisation during muscular exercise, has traditionally been considered the criterion measure of cardiovascular fitness (3,4,6).

However, we are concerned that VO_2max during an exercise test may not consistently measure aerobic capacity in subjects with breathing difficulties.

This study was undertaken to assess whether VO_2max can be used as an index of measuring aerobic capacity under the condition of increased respiratory resistance which constrains minute ventilation (V_E).

Materials and Methods

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

Each subject performed two incremental exercise tests to the limit of tolerance on an electro-magnetically braked cycle ergometer (Lode, Excalibur) on different days: one control (C) and one breathing through an 8 mm bore diameter respiratory resistance (R), which affects both the inspiratory and expiratory sides of breathing.

During the exercise test, following a four minute warm-up period cycling at 20 watts (60 rpm), the work rate was increased by 15 watts each minute and continued to the subjects' limit of tolerance as described by Whipp et al. (7).

Table 1. Physical characteristics of subjects. Values are presented mean (±SD).

Subjects	Age (yr)	Height (cm)	Weight (Kg)
(n=7)	21.1±4.4	175.7±6.3	69.7±7.6

During exercise tests, the subjects breathed through a mouthpiece attached to a low resistance (1.5 cmH_2O at 3 l/sec) and a 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 O_2, CO_2 and N_2. The calibration and validation of the system was performed prior to each study as described by Huszczuk et al. (8). Ventilatory and pulmonary gas exchange variables were estimated using breath-by-breath Beaver algorithm (9). 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 whole test.

The highest point for the VO_2 in response to the maximal exercise effort which characterised a plateau despite further work rate increases was considered the maximal VO_2 (VO_2max), and without a plateau in VO_2 was considered as the peak VO_2 (VO_2peak) (3).

Anaerobic threshold (AT) was estimated non-invasively using the V-slope method (10), which depends upon the increase in CO_2 output due to the excess CO_2 production from bicarbonate buffering of metabolic (chiefly lactic) acidosis compared to the O_2 uptake during the incremental exercise test (11).

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

Results

In both studies, VO_2 increased linearly with increasing work rate until the subjects' maximal exercise tolerance was reached (Figure 1). However, the plateau in VO_2 is not a consistent feature of incremental exercise tests even in the control study at the subjects' maximum effort (Figure 1).

Increased respiratory resistance led to a significant decrease in minute ventilation (V_E) at anaerobic threshold and also at maximal exercise performance (34.8±4.2 l/min and 69.7±6.8 l/min) compared to the control (39.8±6.2 l/min and 118.0±15.2 l/min) (Table 2).

The maximal work rate obtained during incremental exercise was 260±29 W/min in the control and 233±14 W/min in resistance, demonstrating significant difference between the two groups (Table 2, Figure 2). The VO_2 at maximal exercise (VO_2peak) was 3.25±0.40 l/min in the control study and significantly differed from that in the resistance study, i.e. 2.83±0.20 l/min (Table 2, Figure 2).

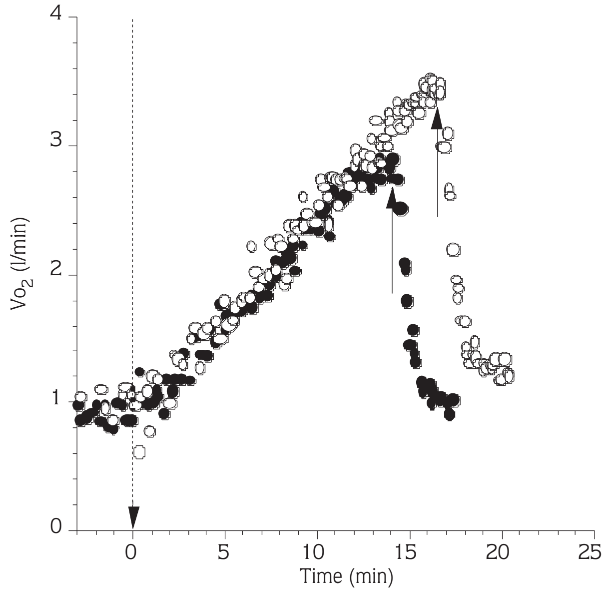

Figure 1. Overlaying plots of oxygen uptake (VO_2) response to the progressively increasing work rate exercise test in the control study (o) and in the increased respiratory resistance study (•) (one representative subject). Vertical broken line represents the onset of the ramp phase. The upward arrows represent the end of the ramp phase.

However, the increased respiratory resistance did not have a significant effect on AT, which reflects the subjects' aerobic capacity (Table 2, Figures 2, 3). There was no significant difference in VO_2 at AT for both tests: 1.80±0.28 l/min for the control and 1.81±0.28 l/min for the resistance studies (Table 2).

Discussion

Non-invasive cardiopulmonary exercise testing provides two objective criteria, VO_2max and AT through which the severity of cardiac failure (4, 6) or pulmonary disease (2,12,13) can be assessed and an optimal exercise training programme (12,14) can be established. As a training protocol, a work rate at 50% of VO_2max (15) or at the AT (16) are the most used critical training intensities. It has been shown that a work rate below 50% of VO_2max provides no measurable benefits (15).

Subject No	VO_2peak (l/min)		WRpeak (l/min)		AT (l/min)		VE_{AT}		VE_{peak}	
	C	R	C	R	C	R	C	R	C	R
1	2.67	2.84	235	245	1.59	1.59	36	31	110	81
2	3.37	2.97	255	235	1.88	1.90	42	39	140	76
3	3.2	2.75	250	230	1.64	1.65	41	32	115	61
4	3.46	2.80	275	235	1.67	1.66	38	32	135	71
5	2.80	2.44	220	205	1.53	1.53	32	32	115	66
6	3.45	3.10	275	255	2.33	2.31	52	42	95	66
7	3.85	2.91	310	235	2.00	2.03	38	36	116	67
Mean	3.25*	2.83	260*	233	1.80	1.81	39.8*	34.8	118.0*	69.7
±SD	0.40	0.20	29	14	0.28	0.28	6.2	4.2	15.2	6.8

* Significantly different from the resistance study (P<0.05)

Table 2. The values for the peak O_2 uptake (VO_2peak), exercising performance (WRpeak) at the end of the ramp phase, O_2 uptake at the anaerobic threshold (AT), minute ventilation (V_E) at the anaerobic threshold (VE_{AT}) and at maximal exercise performance (VE_{peak}) during incremental exercise for the control (C) study and with the increased airway resistance (R).

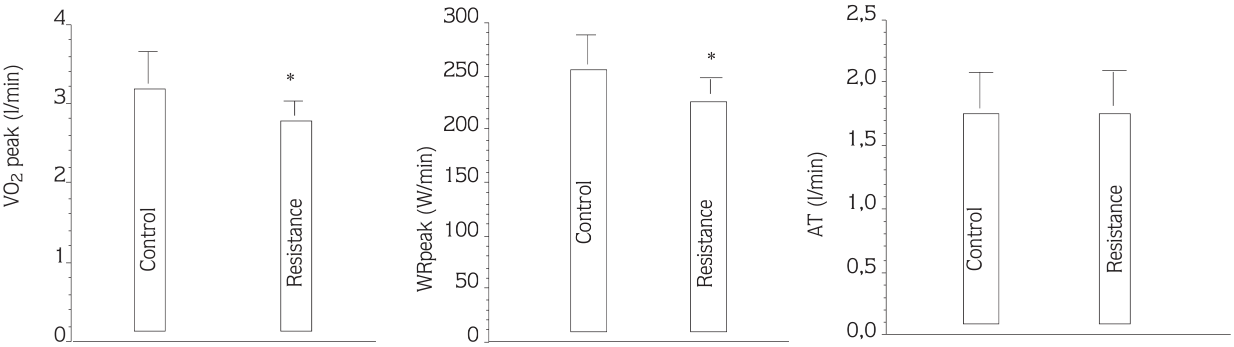

Figure 2. The mean (±SD, n=7) values of peak O_2 uptake (VO_2peak) and exercising performance (WRpeak) and O_2 uptake at the anaerobic threshold (AT) for both the control and resistance studies. * indicates significant difference from the control study.

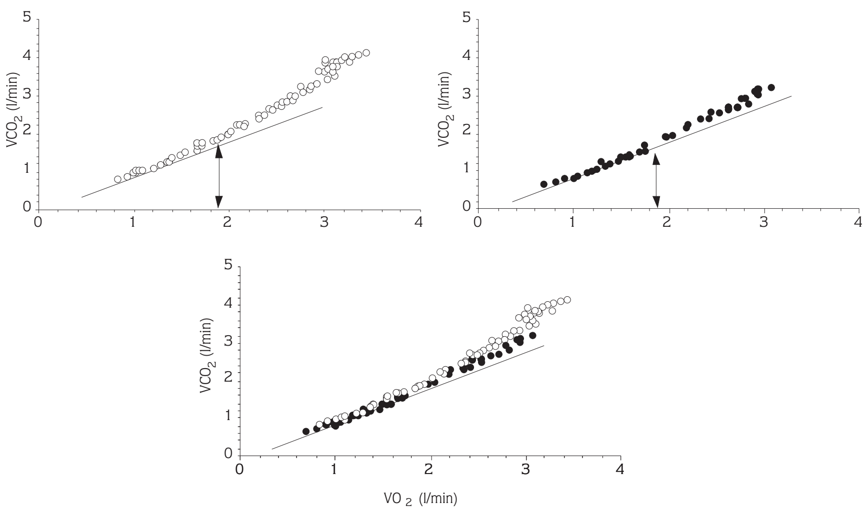

Figure 3. CO_2 output (VCO_2) as a function of O_2 uptake (VO_2) during incremental exercise (V-slope relationships) in the control study (o) and with a high respiratory resistance (•).

Normally, VO_2 increases linearly during incremental exercise (3,7). Furthermore, in the present study, subjects with high respiratory resistance showed similar responses to the control study. However, in the resistance study, subjects were not able to attain the same VO_2 levels as in the control study. It is important to emphazise that in the present study, none of the subjects were able to achieve their VO_2max. It has been observed that the level of attainable VO_2 at the end of the ramp phase (i.e. VO_2peak) can be reduced without altering aerobic capacity under the condition of increased respiratory resistance (Figures 1, 3). In the respiratory resistance study, subjects had to stop the exercise before reaching their maximal performance due to breathlessness, which was not observed in the control study.

The AT, which reflects the activation of anaerobic metabolism and describes the highest VO_2 that can be maintained during prolonged exercise without increase in blood lactate concentration, was not affected by the high respiratory resistance (Figures 2,3). Thus, under the condition of constrained ventilation, the AT actually reflects aerobic capacity rather than VO_2max.

Therefore, AT should be determined systematically in addition to VO_2max during maximal exercise tests to better evaluate physical fitness.

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References

1. American Thoracic Society. Evaluation of impairment/disability secondary to respiratory disorders. Am Rev Respir Dis 133: 1205-9, 1986.
2. Janicki JS, Weber KT, Likoff MJ, Fishman AF. Exercise testing to evaluate patients with pulmonary vascular disease. Am Rev Respir Dis 129: 93-95, 1984.
3. Wasserman K, Hansen JE, Sue DY, Whipp BJ. Principles of exercise testing and interpretation (Eds. J. M. Harris) Lea & Febiger, Second edition, Philadelphia: P: 52-72, 1994.
4. Weber KT, Janicki JS. Cardiopulmonary exercise testing for evaluation of chronic cardiac failure. Am J Cardiol 22A-31A, 1985.
5. Wagner P. New ideas on limitations to VO_2max. Exerc Sports Sci Rev 20: 10-14, 2000.
6. Bruce AR, Kusumi MS, Hosmer D, Wash S. Maximal oxygen intake monographic of functional aerobic impairment in cardiovascular disease. Am Heart J 85: 546-62, 1973.
7. Whipp BJ, Davis JA, Torres F, Wasserman K. A test to determine parameters of aerobic function during exercise. J Appl Physiol 50: 217-21, 1981.
8. Huszczuk A, Whipp BJ, Wasserman K. A respiratory gas exchange simulator for routine calibration in metabolic studies. Eur Respir J 3: 465-8, 1990.
9. Beaver WL, Lamarra N, Wasserman K. Breath-by-breath measurement of true alveolar gas exchange. J Appl Physiol 51: 1662-75, 1981.
10. Beaver WL, Wasserman K, Whipp BJ. A new method for detecting anaerobic threshold by gas exchange. J Appl Physiol 60: 2020-27, 1986.
11. Stringer W, Casaburi R, Wasserman K. Acid-base regulation during exercise and recovery in humans. J Appl Physiol 72: 954-61, 1992.
12. Patessio A, Casaburi R, Prefaut C, Folgering H, Donner C. Exercise training in chronic lung disease: exercise prescription. Eur Respir J 6: 129-46, 1997.
13. Sue DY. Exercise testing in the evaluation of impairment and disability. Clin Chest Med 15: 369-87, 1994.
14. Gaesser GA, Rich RG. Effects of high- and low-intensity exercise training on aerobic capacity and blood lipids. Med Sci Sports Exerc 16: 269-75, 1984.
15. American College of Sports Medicine Position Stand: The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness in healthy adults. Med Sci Sports Exerc 22: 265-70, 1990.
16. Casaburi R. Physiological responses to training. Clin Chest Med 15: 215-27, 1994.