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Effects of Increased Respiratory Resistance on Maximal O₂ Uptake and Anaerobic Threshold during Incremental Exercise Tests

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Abstract: This study was undertaken to assess whether maximal O₂ uptake (VO₂max) 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. VO₂max 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 VO₂ is not a consistent feature of incremental exercise tests even in the control study at the subjects' maximum effort. VO₂ 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 VO₂max during maximal exercise tests to better evaluate physical fitness.

Key Words: O₂ uptake, Anaerobic threshold, Exercise test

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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 O₂ uptake (VO₂max), which is defined as reaching a plateau of VO₂ despite further increases in work rate (5) and which reflects the upper limit of body O₂ uptake (VO₂) and utilisation during muscular exercise, has traditionally been considered the criterion measure of cardiovascular fitness (3,4,6).

However, we are concerned that VO₂max during an exercise test may not consistently measure aerobic capacity in subjects with breathing difficulties.

This study was undertaken to assess whether VO₂max 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 cmH₂O 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 O₂, CO₂ and N₂. 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 VO₂ in response to the maximal exercise effort which characterised a plateau despite further work rate increases was considered the maximal VO₂ (VO_{2max}), and without a plateau in VO₂ was considered as the peak VO₂ (VO_{2peak}) (3).

Anaerobic threshold (AT) was estimated non-invasively using the V-slope method (10), 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 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, VO₂ increased linearly with increasing work rate until the subjects' maximal exercise tolerance was reached (Figure 1). However, the plateau in VO₂ 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

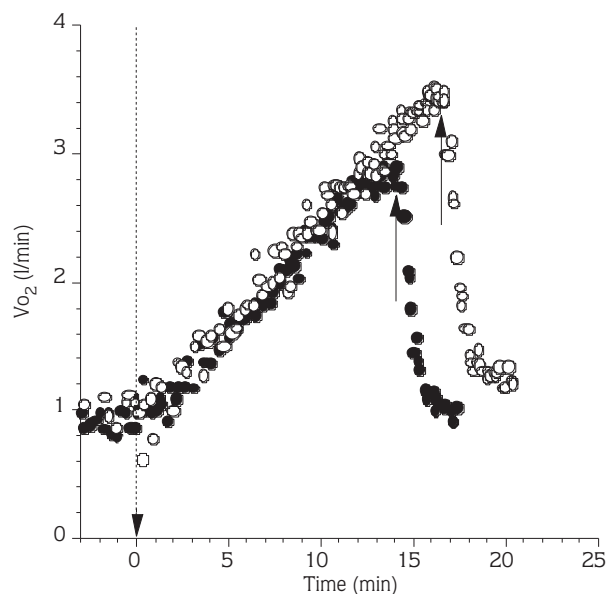


Figure 1. Overlaying plots of oxygen uptake (VO₂) response to the progressively increasing work rate exercise test in the control study (○) and in the increased respiratory resistance study (●) (one representative subject). Vertical broken line represents the onset of the ramp phase. The upward arrows represent the end of the ramp phase.

W/min in resistance, demonstrating significant difference between the two groups (Table 2, Figure 2). The VO₂ 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).

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 VO₂ 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 ₂ peak (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 |

Table 2. The values for the peak O₂ uptake (VO₂peak), exercising performance (WRpeak) at the end of the ramp phase, O₂ uptake at the anaerobic threshold (AT), minute ventilation (V_E) at the anaerobic threshold (V_{EAT}) and at maximal exercise performance (V_{Epeak}) during incremental exercise for the control (C) study and with the increased airway resistance (R).

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

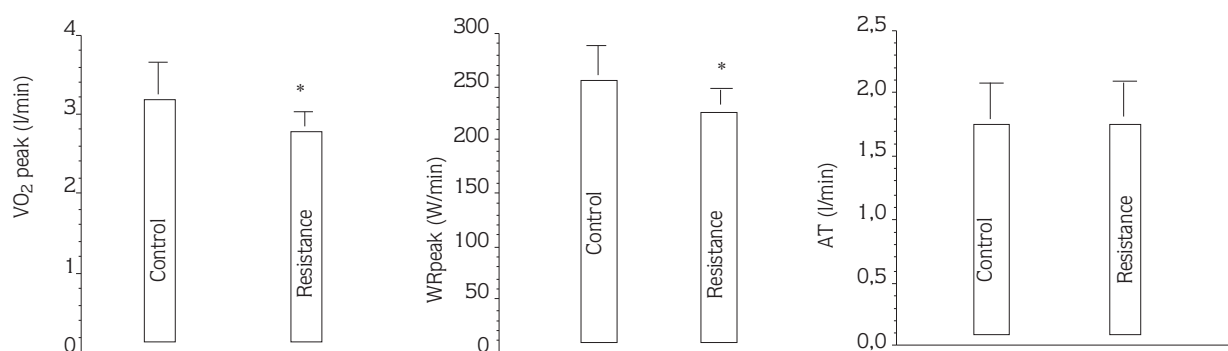


Figure 2. The mean (\pm SD, n=7) values of peak O₂ uptake (VO₂peak) and exercising performance (WRpeak) and O₂ uptake at the anaerobic threshold (AT) for both the control and resistance studies. * indicates significant difference from the control study.

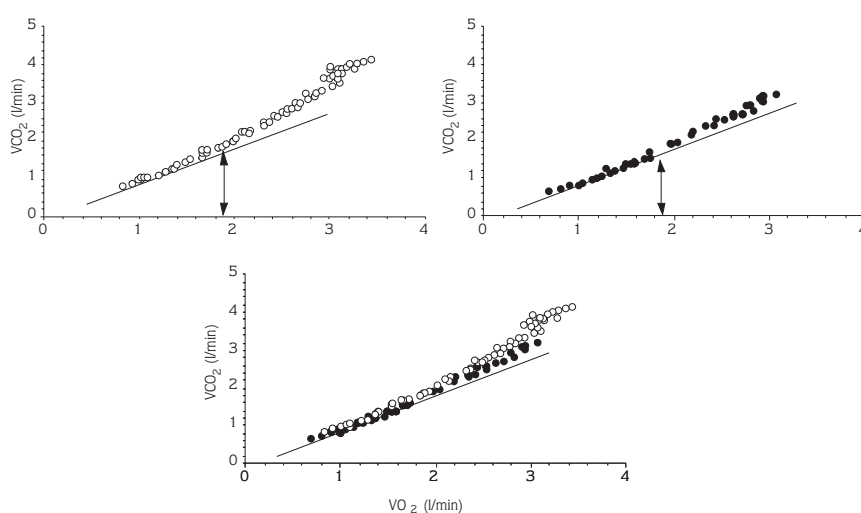


Figure 3. CO₂ output (VCO₂) as a function of O₂ uptake (VO₂) during incremental exercise (V-slope relationships) in the control study (o) and with a high respiratory resistance (●).

Normally, VO₂ 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 VO₂ levels as in the control study. It is important to emphasize that in the present study, none of the subjects were able to achieve their VO₂max. It has been observed that the level of attainable VO₂ at the end of the ramp phase (i.e. VO₂peak) 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 VO₂ 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 VO₂max.

Therefore, AT should be determined systematically in addition to VO₂max during maximal exercise tests to better evaluate physical fitness.

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