Effect of exercise mode on oxygen uptake and blood gases in COPD patients

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Summary Patients with chronic obstructive pulmonary disease (COPD) are characterised by decreased exercise tolerance, and, more variably, exercise induced hypoxaemia (EIH). Evaluation of physical work capacity and physiological responses to exercise may be performed by various procedures, but there are diverging opinions as to which exercise test should be preferred. In the current study, oxygen uptake and arterial blood gases in COPD patients have been compared during sub-maximal and maximal exercise on treadmill and ergometer bicycle.

Treadmill exercise resulted in higher peak oxygen uptake than bicycle exercise (1111 ± 235 vs. 987 ± 167 ml min\(^{-1}\), \(P<0.02\)), while the plasma lactate levels were higher during cycling (1.8 ± 0.8 vs. 3.8 ± 1.7 mmol l\(^{-1}\), \(P<0.001\)). Neither carbon dioxide output, ventilation, nor rate of perceived exertion (Borg RPE scale) showed significant differences between the two modes of exercise. The EIH during both maximal (\(\Delta SaO_2 = -5.6 \pm 4.2\) vs. \(-3.4 \pm 5.1\%\)) and sub-maximal exercise was more pronounced during treadmill walking than during cycling.

The present study indicates that the \(\text{VO}_{2\text{peak}}\) in COPD patients is higher, the maximal lactate concentrations lower and the development of EIH more pronounced when exercise testing is performed on a treadmill than on a bicycle ergometer.

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Introduction

Patients with chronic obstructive pulmonary disease (COPD) are characterised by decreased exercise tolerance, and, more variably, exercise induced hypoxaemia (EIH).\(^1\) Evaluation of physical work capacity and physiological responses to exercise, including EIH, can be used clinically for establishing the causes of exercise intolerance,\(^2\) for preoperative evaluation,\(^3\) for evaluating the effect of therapeutic interventions and rehabilitation,\(^4,5\) and for evaluating the use of supplementary oxygen during exercise.\(^5,6\)

Exercise tests may be performed by various procedures, most commonly employing either a walking protocol (treadmill and different walk tests) or a standardised ergometer bicycle protocol.\(^7\) There are diverging opinions with regard to which exercise test should be used to determine peak oxygen uptake (\(\text{VO}_{2\text{peak}}\)) and development of EIH in COPD patients.\(^2,7-11\) Because bicycle testing allows direct quantification of workload, and also for practical and economical reasons, many laboratories prefer bicycle ergometers to treadmill testing.\(^8-10\) However, this exercise mode may create problems for some COPD patients that are unable to reach their \(\text{VO}_{2\text{peak}}\) because of leg fatigue on a bicycle ergometer.\(^11,12\) Therefore, we have
studied whether exercise testing of COPD patients by use of these two modalities (treadmill and ergometer bicycle) gave comparable results with regard to (1) peak values of oxygen uptake ($V_{O2\text{peak}}$), carbon dioxide output ($V_{CO2}$), maximal ventilation ($V_{e\text{peak}}$), blood lactate, cardiac frequency ($f_{C\text{peak}}$), blood pressure, and perceived exertion and (2) the development of EIH, both at peak and sub-maximal exercise corresponding to a physical effort comparable with daily life activity.

**Materials and methods**

**Study population**

 Twelve patients (10 male and 2 female) suffering from COPD according to the criteria of the American Thoracic Society, and with a forced expiratory volume in one second (FEV$_1$) <50% of predicted, were recruited for the study. At the time of testing, all were in a stable phase of their disease. Three patients with mild hypertension received calcium-blockers, nine patients used inhaled, and two used oral (5 and 15 mg/day, respectively) corticosteroids. None had clinical signs of left ventricular dysfunction. The results for the two patients on oral steroids did not differ overtly from the rest of the group. Patients with coexisting medical problems that might influence their physical capacity were excluded from the study.

 A written informed consent was obtained from all participants, and the study was approved by the regional committee for medical ethics.

**Lung function tests**

 Each patient was examined on two separate days. On day one the following lung function measurements were performed: forced vital capacity (FVC), FEV$_1$ and maximal voluntary ventilation (MVV) were determined with a bell spirometer. The MVV measured at rest before each exercise was used in calculating the ventilatory reserve. The single-breath transfer factor of the lung for carbon monoxide ($T_{L,CO}$) was determined by means of a Hewlett-Packard single-breath diffusion system (Hewlett-Packard, Massachusetts, USA) (Table 1).

**Experimental procedure**

 On day two, the exercise tests on treadmill and bicycle were performed in random order, and to the patients symptom limited maximum, with at least 1 h rest between each test. A 12 channel electrocardiogram (ECG) (Mingograph 7 Siemens-Elema, Stockholm, Sweden) was taken prior to the experiment, and a catheter was inserted in a radial artery.

 All measurements were carried out both at rest and during exercise. During exercise the patients were continuously monitored by pulse oximetry using a finger-probe (SatTrak, SensorMedics, Bilthoven, the Netherlands), and heart rhythm was monitored on a cardioscope (Hellige, Freiburg, Germany).

 Ventilation ($V_{e}$), oxygen uptake ($V_{O2}$) and carbon dioxide output ($V_{CO2}$) were continuously measured with an Oxycon Champion (Jaeger-Toennies, Wurtzburg, Germany), and peak $V_{O2}$ (ml min$^{-1}$) were defined as the highest measured value during 30 s.

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**Table 1** Lung function and arterial blood gases in 12 subjects with chronic obstructive pulmonary disease

<table>
<thead>
<tr>
<th></th>
<th>Mean ± 1SD</th>
<th>Range</th>
<th>% predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>55 ± 11</td>
<td>40–74</td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>176 ± 8</td>
<td>166–189</td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>72 ± 12</td>
<td>53–95</td>
<td></td>
</tr>
<tr>
<td>FVC (l)</td>
<td>3.4 ± 1.0</td>
<td>2.1–5.4</td>
<td>79 ± 20</td>
</tr>
<tr>
<td>FEV$_1$ (l min$^{-1}$)</td>
<td>1.0 ± 0.2</td>
<td>0.6–1.4</td>
<td>32 ± 8</td>
</tr>
<tr>
<td>FEV$_1$/FVC (%)</td>
<td>28 ± 7</td>
<td>16–39</td>
<td></td>
</tr>
<tr>
<td>MVV (l min$^{-1}$)</td>
<td>45 ± 8</td>
<td>30–55</td>
<td></td>
</tr>
<tr>
<td>$T_{L,CO}$ (mmol min$^{-1}$ kPa$^{-1}$)</td>
<td>4.6 ± 1.3</td>
<td>2.4–6.1</td>
<td>48 ± 11</td>
</tr>
<tr>
<td>$P_{a,O2}$ (kPa)</td>
<td>10.4 ± 2.0</td>
<td>7.7–14.0</td>
<td></td>
</tr>
<tr>
<td>$Sa,O2$ (%)</td>
<td>95.2 ± 2.3</td>
<td>89.9–98.0</td>
<td></td>
</tr>
<tr>
<td>$P_{a,CO2}$ (kPa)</td>
<td>5.0 ± 0.6</td>
<td>4.1–6.2</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>7.42 ± 0.03</td>
<td>7.37–7.47</td>
<td></td>
</tr>
<tr>
<td>Lactate (mmol/l)</td>
<td>1.4 ± 0.7</td>
<td>0.5–2.6</td>
<td></td>
</tr>
</tbody>
</table>

Values are presented as mean ± 1 standard deviation. FVC: forced vital capacity; FEV$_1$, forced expiratory volume in one second; MVV: maximal voluntary ventilation in one minute; $T_{L,CO}$: Single-breath transfer factor for the lung for carbon monoxide; $P_{a,O2}$ and $P_{a,CO2}$: arterial oxygen and carbon dioxide tension, respectively; $Sa,O2$: arterial oxygen saturation.
Ventilatory reserve was defined as the per cent difference between maximal exercise ventilation and MVV. Arterial blood samples were drawn from a catheter in the radial artery at rest and during the last 15 s of each exercise step. Arterial $\text{PO}_2$, $\text{PCO}_2$, pH and $\text{SO}_2$ were determined using a Radiometer ABL 520 (Copenhagen, Denmark). Lactate concentration in plasma were analysed with an enzymatic technique (Cobas Bio, Basel, Switzerland).

The arterial blood pressure was recorded through the catheter in the radial artery using a Mingograph 7 and a Baxter TruWave disposable pressure transducer (Glendale, CA, USA).

During the last half minute of each exercise step, subjects were asked to rate their perceived exertion using the Borg RPE-scale (range 6–20).

**Ergometer bicycle exercise:** After 5 min of unloaded pedalling on an electrical braked ergometer bicycle (Ergoline 900, Jaeger-Toennies, Wurtzburg, Germany), the workload was increased to 10 W. Thereafter, the workload was increased by 5 W min$^{-1}$ during the first 2 min, and then increased by 10 W every 4 min until exhaustion. The pedalling rate were 60 revolutions min$^{-1}$.

**Treadmill exercise:** The patients walked on a treadmill with 0% inclination at an initial speed of 1.2 km h$^{-1}$. The speed was increased by 0.6 km h$^{-1}$ every 4 min until symptom limited maximum.

**Sub-maximal exercise:** Arterial blood gases during ergometer cycling at 30 W were compared to blood gas values obtained during treadmill exercise at the corresponding treadmill $\text{VO}_2$ values. A workload of 30 W was $59 \pm 15\%$ of maximal cycle workload, and the bicycle $\text{VO}_2$ values corresponded to a walk speed on the treadmill from 1.2 to 2.4 km h$^{-1}$, or 70% of $\text{VO}_2\text{peak}$.

### Statistical analysis

The results were expressed as mean $\pm 1\text{SD}$. Paired $t$-tests were used to evaluate differences in variables between parameters at treadmill and bicycle at rest and during exercise. Two-tailed $P<0.05$ were considered statistically significant.

### Results

The patient characteristics and results of the lung function tests are presented in Table 1. The FVC was $79 \pm 20\%$ of predicted (mean $\pm 1\text{SD}$), while the FEV$_1$ was $32 \pm 8\%$ of predicted values.

Treadmill exercise resulted in a significantly higher $\text{VO}_2\text{peak}$ than bicycle exercise ($1111 \pm 235\text{ml min}^{-1}$ vs. $987 \pm 167\text{ml min}^{-1}$, $P<0.02$, Fig. 1a). Neither CO$_2$ output (Fig. 1b), nor ventilation (Fig. 1c) showed significant differences between the two modes of exercise. The ventilatory reserve was not significantly different between treadmill (23$\pm$13%) and the bicycle (22$\pm$15%) exercise, and there was a significant correlation ($r=0.75$, $P<0.01$) between the ventilatory reserves at maximum workload in the two exercise modes.

The cardiac frequency (Fig. 1d) and systolic blood pressure (Fig. 1e) were similar during the two modes of exercise, and there was no difference in perceived exertion between treadmill walking and ergometer bicycling at peak exercise (Borg $18.5 \pm 0.5$ vs. $18.3 \pm 0.6$). At maximal exercise, the plasma concentration of lactate during treadmill exercise was significantly lower than during bicycle exercise ($1.8 \pm 0.8\text{mmol l}^{-1}$ vs. $3.8 \pm 1.7\text{mmol l}^{-1}$, $P<0.0002$, Fig. 1f), and bicarbonate concentrations were higher ($P<0.005$) on treadmill (24.7$\pm$1.9 mmol l$^{-1}$) than on bicycle (23.0$\pm$2.7 mmol l$^{-1}$). Lactate concentrations were negatively correlated with bicarbonate concentrations ($r=-0.78$, $P<0.01$) at maximum cycle exercise, but not on treadmill. RER ($V\text{CO}_2/V\text{O}_2$) values were...
significantly correlated with lactate levels ($r = 0.67, P < 0.05$), but not with bicarbonate.

The arterial blood gases at rest were similar in a standing (treadmill) and a sitting (cycle) position (Table 1 and Fig. 2). During maximal exercise, however, the EIH was more pronounced when the patients were walking on a treadmill ($\Delta Pa,O_2 = 2.4 \pm 1.5$ kPa) than when they were cycling on an ergometer bicycle ($\Delta Pa,O_2 = 1.0 \pm 1.9$ kPa, $P < 0.002$, Fig. 2a). The $\Delta S_a,O_2$ was $-5.6 \pm 4.2\%$ during treadmill exercise, compared to $-3.4 \pm 5.1\%$ on the bicycle ($P < 0.002$, Fig. 2b). At peak exercise, $Pa,CO_2$ was significantly higher during treadmill exercise than during bicycling ($5.9 \pm 0.5$ vs. $5.6 \pm 0.6$, $P < 0.04$) (Fig. 2c).

During sub-maximal exercise, i.e. physical effort comparable with daily life activity, there was no significant difference in the decline in $Pa,O_2$ on the treadmill ($\Delta Pa,O_2 = -0.9 \pm 1.5$ kPa) and on the ergometer bicycle ($\Delta Pa,O_2 = -0.2 \pm 1.4$ kPa, Fig. 2a) ($P < 0.08$), while a small difference in $S_a,O_2$ was observed ($\Delta S_a,O_2 = -2.6 \pm 4.7\%$ vs. $-1.7 \pm 5.2\%$, $P < 0.02$, Fig. 2b). No significant difference in $\Delta Pa,CO_2$ was observed between the two modes of sub-maximal exercise (Fig. 2c).

**Discussion**

The current study indicates that the $VO_{2peak}$ in COPD patients is higher when exercise testing is performed on a treadmill than on a bicycle ergometer, whereas the increase in plasma lactate concentration is more pronounced during cycling. Development of EIH also seems to be dependent on the mode of exercise—the decrease in both $Pa,O_2$ and $S_a,O_2$ was more pronounced during exercise on a treadmill than on an ergometer bicycle.

The higher $VO_{2peak}$ during treadmill exercise in this study is in accordance with what is found in healthy subjects.\(^2,10,11,15,16\) This has been explained with familiarization with walking and running and the use of larger muscle groups.\(^2\) In two previous studies on COPD patients, however, no difference in $VO_{2peak}$ between the two modes of exercise was observed.\(^17,18\) In one of the studies,\(^17\) the exercise modes were the same as in our study. In the other study the walking exercise was a modified shuttle walk and therefore not directly comparable with the current study.\(^18\) Bicycle exercise may have been an unusual form of exercise for our patients. However, the maximal ventilation ($Ve_{peak}$) and ventilatory reserves were similar in the two modes of exercise, as also found by Palange\(^18\) and Mathur,\(^17\) and we believe that this argues against a change in the cause of exertion from dyspnea on treadmill to leg fatigue on bicycle.

At maximum effort the respiratory exchange ratio (RER) was higher during bicycle than during treadmill exercise, since $VCO_{2peak}$, but not $VO_{2peak}$, was higher during bicycling. Although the correlation with lactate levels suggest that the higher RER values during cycling were caused by a lactate-driven depletion of bicarbonate stores, we found no correlation between RER and bicarbonate levels at maximum exercise, in either walking or cycling. Higher RER values in cycling compared to walking is in agreement with previous reports, although we did not find as high RER values during cycling as those reported by Palange et al.\(^18\) Also, we could not confirm the higher $Ve/VCO_2$ ratio during treadmill walking that was reported by these authors.

In agreement with previous reports on COPD patients,\(^18,20\) we found that the decrease in $S_a,O_2$ was more pronounced during treadmill than during bicycle exercise. The explanation for this
difference, however, differs between studies. Cockcroft et al.\(^\text{19}\) suggested that the differences in \(P_{a,O_2}\) were caused mainly by differences in ventilation, which in turn were caused by higher rates of lactate production during cycling. Although the peak \(V_{e}\) was not different between exercise modes in our study, the \(V_{e,\text{peak}}/V_{O_2,\text{peak}}\) and lactate levels were higher during bicycle exercise. The higher ventilatory equivalent would lead to a higher alveolar \(P_{a,O_2}\), in agreement with Cockcroft et al.\(^\text{19}\) On the other hand, Palange et al.\(^\text{18}\) found that alveolar ventilation rates were similar in the two modes of exercise in spite of higher lactate levels during cycling, and suggested rather that the difference in \(P_{a,O_2}\) was due to higher rates of dead space ventilation during the shuttle walk test. It is possible that, as suggested by Palange et al.,\(^\text{18}\) the arm movements during the free walking in the shuttle walk, as opposed to having arms resting on bicycle handles or the supports on the sides of the treadmill, contributes to this difference.

Although some everyday activities may come close to the maximum work capacity of seriously affected lung patients, we believe that evaluating the need for \(O_2\) supply in daily life should include testing responses to sub-maximal workloads in addition to maximal effort. We compared \(P_{a,O_2}\) measured at the workload of 30 W on the bicycle, with \(P_{a,O_2}\) at slow walking, at a \(V_{O_2}\) corresponding to 30 W bicycle workload. At this level of \(V_{O_2}\) we found no difference in \(P_{a,O_2}\) between the two work modes, and only a minor difference in \(S_{a,O_2}\), which implies that work mode affects \(EIH\) less at sub-maximal than at peak exercise. There are several practical advantages of using an ergometer bicycle rather than a treadmill in cardiopulmonary exercise testing.\(^\text{9}\) However, bicycle testing underestimates both the \(V_{O_2,\text{peak}}\) and the degree of \(EIH\) in COPD patients. Therefore, if possible, the more physiological way of exercising that is obtained on a treadmill should probably be preferred when evaluating these parameters in this group of patients.

References