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Comparison of arm and leg ergometry in patients with moderate chronic obstructive lung disease

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ABSTRACT Exercise testing is traditionally performed with leg exercise on either a treadmill or a bicycle ergometer. Many of these tests are terminated before dyspnoea occurs because of leg fatigue, arthritic pain, or claudication. A study was carried out to determine whether arm ergometry testing might serve as an alternative method to leg testing in eight patients with chronic obstructive lung disease. The patients had mild to moderate dyspnoea on exertion and required bronchodilator treatment. They had smoked an average of 62 pack years and had a mean FEV_1 of 1·88 l. Arm and leg ergometry yielded similar levels of maximum ventilation (arm 47·2, leg 48·6 l/min), maximum heart rates (126 *v* 124 beats/min), maximum tidal volume (1·5 *v* 1·6 l), and respiratory rate (30 *v* 29 breaths/min); but maximum oxygen consumption (1120 *v* 966 ml/min), maximum power output (62 *v* 26 w), and oxygen pulse (9·1 *v* 7·8 ml/beat) were all higher with leg than with arm ergometry. In addition, ventilation and heart rate at a given level of oxygen consumption were higher for arm than for leg work during both submaximal and maximal exercise. It is concluded that arm ergometry offers an alternative testing method to leg testing in patients with moderate chronic obstructive lung disease.

Introduction

The optimal termination criterion for exercise testing of patients with chronic obstructive lung disease is dyspnoea.[1] Many exercise tests are terminated for reasons other than dyspnoea, in some because of angina or arrhythmias, and in others because of leg fatigue, claudication, pain from arthritis, or inability to ride a bicycle ergometer. Because of this, documentation of pulmonary dysfunction is sometimes not possible, and analysis of data from the exercise testing may be difficult. A mode of exercise testing in which leg fatigue or pain does not prevent the ventilatory system being adequately stressed might be helpful.

Arm exercise in normal individuals is associated with a maximum oxygen consumption 70–85% of that generated by leg exercise.[2] Heart rate and ventilation ($\dot{V}e$) also reach higher levels with leg testing.[3] The rate of increase in both heart rate and ventilation with increases in oxygen consumption ($\dot{V}O_2$) is, however, greater with arm work. Thus exercise testing using the arms in normal subjects causes a higher level of ventilation than leg exercise when comparisons are made at the same level of oxygen consumption.[4] In addition, the oxygen pulse is lower during arm exercise. Although the physiological response to arm ergometry has been well described for normal subjects, there is little information in patients with chronic obstructive lung disease. This study was performed to compare indices of cardiopulmonary function during arm and leg ergometry in such patients.

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Methods

Eight male patients with stable chronic obstructive lung disease, mean age 62 (SD 8) years, participated in the study. All patients required bronchodilators for symptom control: inhaled beta agonists in six patients, oral theophylline in six, and oral corticosteroids in two. The patients had had no exacerbation of respiratory symptoms in the month preceding the study. All patients had moderate and stable airflow obstruction (FEV_1/FVC 45–60%) with no evidence of bronchoconstriction after exercise. Patients with cardiovascular risk factors and clinical evidence of cardiovascular disease and those requiring supplemental oxygen were excluded from the study. Informed consent was obtained from each subject before the start of the study.

The study was performed on two days one to three days apart. Inhaled beta agonists were withheld for four hours before tests; oral theophylline and corticosteroids were taken as usual. Baseline spirometry, arterial blood gas analysis, practice on both ergometers, and either the arm or the leg ergometer test (chosen randomly) took place on the first day. On the second day the other ergometer test and spirometry before and after exercise were performed.

The arm and leg exercise tests were symptom limited maximal evaluations. Initially, the patient pedalled or cranked the ergometer for one minute with no added resistance. The pedalling and cranking frequency was 60 revolutions a minute. The power output was then increased each minute by 5 watts for arm and 15 w for leg tests; the work levels were chosen to achieve similar durations of exercise. As the arms have about one third the muscle mass of the legs, power output increments of one third of those used for leg exercise have been shown to achieve similar exercise duration.[5-7] The exercise tests were terminated when the patient was exhausted or when there were signs or symptoms of exertional intolerance, as defined by the American College of Sports Medicine.[8]

A Godart Lanooy electronically braked cycle ergometer was used for both arm and leg testing. Ventilatory flow was measured by a Fleisch No 3 pneumotachograph with Validyne transducer and carrier amplifier. Expired oxygen and carbon dioxide were sampled continuously from a 5 litre mixing chamber by a Perkin-Elmer MGA-1100 medical gas analyser. During exercise heart rate (beats/min) and expired oxygen and carbon dioxide concentrations were measured, and the values used to calculate oxygen consumption, carbon dioxide production ($\dot{V}CO_2$), and the respiratory exchange ratio (R) every 30 seconds. The maximum oxygen uptake was chosen as the highest value obtained at any time. Flow measurements were integrated to obtain tidal volume (VT), ventilation (l/min), and respiratory rate (breaths/min). The ventilatory responses during submaximal levels of arm and leg work were compared at a $\dot{V}O_2$ of 800 ml/min, a value that would be attained by the patients during both forms of exercise. The ventilation at a $\dot{V}CO_2$ of 700 ml/min was also analysed. The pattern of breathing at submaximal workloads was analysed by measuring tidal volume and respiratory rate at comparable levels of ventilation during arm and leg ergometry.

Heart rate was monitored with a Hewlett-Packard 78210A cardiotachograph, 78312A oscilloscope, and 76826B strip recorder. Oxygen pulse was calculated by dividing the maximum oxygen consumption at a given workload by heart rate at the end of that workload. Arterial oxygen saturation was monitored with a Hewlett-Packard 47201A ear oximeter. The mechanical efficiency and static components of arm exercise were controlled by a five point restraint system and back board to minimise movement of the upper torso.[9] The arm ergometer was placed at shoulder height.

Spirometry was performed with a dry rolling seal spirometer (Gould 5000IV) and lung volumes determined by body plethysmography (CPI 2000). Maximum voluntary ventilation was performed for 12 seconds and multiplied by 5 to give values in terms of l/min. The single breath diffusing capacity (transfer factor) for carbon monoxide (TLCO) was measured with the Gould 5000IV. Predicted normal values for forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and maximal voluntary ventila-

Table 1 *Smoking history, dyspnoea, and pulmonary function in the patients studied (percentages of predicted values in parentheses)*

Patient No	*Smoking history (pack years)*	*Dyspnoea grade**	*FVC (l)*	*FEV_1 (l)*	*MVV (l/min)*	*FRC (l)*	*TLCO (ml mm Hg^{-1} min^{-1})*
1	94	1	3·91 (91)	1·83 (59)	79 (59)	5·08 (149)	18·8 (85)
2	90	3	3·33 (71)	1·57 (47)	55 (42)	5·31 (136)	8·0 (36)
3	40	2	2·92 (66)	1·76 (55)	47 (34)	4·75 (154)	29·3 (111)
4	88	1	3·58 (76)	2·06 (63)	82 (58)	4·03 (115)	19·1 (78)
5	35	2	3·28 (87)	1·58 (65)	59 (54)	4·98 (140)	13·5 (84)
6	36	1	4·29 (92)	2·26 (68)	81 (57)	3·53 (88)	7·8 (37)
7	70	1	4·00 (89)	2·18 (68)	83 (60)	4·18 (110)	19·7 (94)
8	40	1	3·96 (97)	2·09 (75)	74 (61)	4·12 (123)	13·2 (67)
Mean	62		3·56 (81)	1·88 (62)	70 (53)	4·50 (126)	16·2 (74)
SD ±	26		0·68	0·30	14	0·62	7·1

*1—shortness of breath walking up hills; 2—shortness of breath while walking round one block; 3—shortness of breath while walking around the house.
Conversion: Traditional to SI units—TLCO: 1 ml mm Hg^{-1} min^{-1} = 0·335 ml kPa^{-1} min^{-1}.
FVC—forced vital capacity; MVV—maximum voluntary ventilation; FRC—functional residual capacity; TLCO—carbon monoxide transfer factor.

Table 2 *Mean (SEM) respiratory and cardiac responses to maximal arm and leg exercise*

	Arm	*Leg*	*p*
$\dot{V}e$ (l/min)	47·2 (9·9)	48·6 (10·0)	NS
V_T (l)	1·5 (0·3)	1·6 (0·4)	NS
Respiratory rate (breaths/min)	30·4 (4·2)	28·9 (5·4)	NS
R	1·00 (0·09)	0·97 (0·09)	NS
Power output (w)	26 (10)	62 (27)	<0·001
$\dot{V}O_2$ (ml/min)	966 (189)	1120 (215)	<0·02
$\dot{V}e/\dot{V}O_2$	49·6 (10·1)	44·2 (9·9)	<0·02
$\dot{V}e/\dot{V}CO_2$	49·5 (9·2)	44·8 (7·1)	<0·01
Heart rate (beats/min)	126 (19)	124 (21)	NS
Oxygen pulse (ml/beat)	7·8 (1·8)	9·1 (1·5)	<0·02
pH	7·37 (0·05)	7·38 (0·05)	0·09
$PaCO_2$ (mm Hg)	33 (6)	35 (7)	NS
PaO_2 (mm Hg)	85 (13)	80 (18)	NS
HCO_3^- (mg/dl)	18 (2)	20 (2)	0·1

*n = 4 for pH, $PaCO_2$, PaO_2, and HCO_3^-; n = 8 for all other measurements.
$\dot{V}e$—ventilation; V_T—tidal volume; $\dot{V}O_2$—oxygen consumption; $\dot{V}CO_2$—carbon dioxide production; $PaCO_2$—arterial carbon dioxide tension; PaO_2—arterial oxygen fusion; HCO_3^-—bicarbonate.

tion (MVV) were obtained from Morris,[10] those for functional residual capacity (FRC), residual volume (RV), and total lung capacity (TLC) from Goldman and Becklake,[11] and values for TLCO from the Intermountain Thoracic Society.[12] Arterial blood gases were drawn before and after arm and leg exercise in four individuals.

Statistical analysis of data was performed with Student's two tailed *t* test for paired data. In addition to parametric statistical analysis the data were analysed by non-parametric methods. The results of parametric and non-parametric analyses were identical, so we report the parametric analysis only.

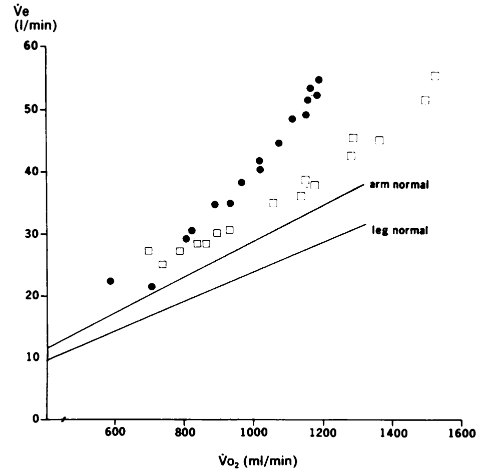

Fig 1 *Ventilation ($\dot{V}e$) in relation to oxygen consumption ($\dot{V}O_2$) in one patient during arm (●) and leg (□) ergometry. Normal regression lines are derived from published reports.*[11 12 19]

Table 3 *Maximal levels of ventilation during arm and leg exercise*

Patient No	*$\dot{V}e$ (arm) (l/min)*	*$\dot{V}e$ (leg) (l/min)*
1	54·6	55·5
2	32·5	44·5
3	42·4	35·8
4	45·6	40·1
5	49·8	37·9
6	40·0	55·3
7	65·5	63·6
8	46·7	55·1

Results

The results of individual pulmonary function tests and demographic data are shown in table 1. All subjects had substantial smoking histories, dyspnoea on exertion, and mild to moderate decrements in pulmonary function. The mean values for the maximal responses to arm and leg exercise are shown in table 2. There were no significant differences in ventilation, tidal volume, respiratory rate, heart rate, or respiratory exchange ratio at maximal exercise between arm and leg exercise. The mean maximum oxygen consumption for arm exercise was 86% of the value for leg exercise (966 *v* 1120 ml/min; $p < 0·02$), and maximal power output was significantly lower for arm than for leg exercise (26 *v* 62 w; $p < 0·001$). The ventilatory equivalents for oxygen and carbon dioxide during maximal arm exercise were therefore greater than that for leg exercise (49·6 and 49·5 *v* 44·2 and 44·8; $p < 0·02$ and $<0·01$). The maximal oxygen pulse was lower during arm exercise ($p < 0·02$). In the four patients studied there was a trend for arm exercise to be associated with a lower pH and bicarbonate concentration ($p = 0·09$ and 0·10).

Differences between arm and leg exercise were also present at submaximal levels of oxygen consumption. Figure 1 shows the ventilatory response to arm and leg exercise in a single subject compared with predicted values.[6 13] When the ventilation levels of each patient at a comparable level of work (fig 1) were compared, the values tended to be higher for arm work ($p = 0·07$). When oxygen pulse data were analysed in a similar manner, the values for arm work were lower than those for leg work ($p < 0·05$). There was, however, no difference between arm and leg ergometry in the values for tidal volume and respiratory rate response to submaximal exercise.

The maximal ventilatory responses for arm and leg exercise achieved by individual patients are shown in table 3. Four of the eight patients had higher levels of ventilation during arm exercise and described leg fatigue as the factor limiting exercise. During arm exercise two patients identified dyspnoea as the only symptom limiting exercise; two patients, however, also included arm fatigue as a limiting factor.

Discussion

The differences between arm and leg exercise in normal subjects are well documented; there are no similar comparisons, however, in patients with chronic obstructive lung disease. We found both similarities and differences between the results of arm and of leg testing in patients with chronic obstructive lung disease and between our results and those previously reported for normal subjects. In patients with chronic obstructive lung disease the maximum ventilation and maximum heart rate achieved with arm ergometry were similar to those generated by standard leg ergometry. The cardiac response differs from that seen in normal subjects. The reason for this difference probably lies in the fact that exercise in patients with chronic obstructive lung disease is limited by ventilation, so that subjects are unable to reach their age predicted maximum heart rates. The $\dot{V}e$/MVV of 72%[14] and the breathing reserve of 21 l/min[15] in our patients are consistent with a ventilatory limitation to exercise.

Although the maximum ventilation and heart rate achieved by arm and leg ergometry are similar, some of the other measurements we made during exercise were different. Arm ergometry was associated with a lower maximum oxygen consumption and with a lower power output than leg ergometry. These findings are similar to those described in normal subjects. This is not surprising since the volume of the leg musculature is considerably greater than that of the arms, allowing the performance of greater levels of exercise.

Ventilation at a given level of oxygen consumption was higher with arm than with leg exercise in our patients. This has also been observed in normal individuals.[4] It has been suggested that the increased level of ventilation may be due to a greater dependence on glycolytic or anaerobic metabolism with arm ergometry owing to the use of smaller muscles, more recruitment of type II fibres, or sustained contractions of trunk and forearm muscles during arm exercise.[16 17] The increase in ventilation with arm ergometry has been shown to occur before the accumulation of lactate.[7 18] Our findings are consistent with this (fig 1).

Previous studies of the pattern of breathing during arm and leg ergometry in normal subjects have led to conflicting results. In one study arm ergometry with a shoulder restraint and harness was associated with a smaller tidal volume and higher respiratory rate than was leg ergometry.[9] A similar study, however, which did not use a restraining device, found no differences in tidal volume and respiratory rate responses between arm and leg testing.[18] Our results are similar to the second study and suggest that arm and leg testing are

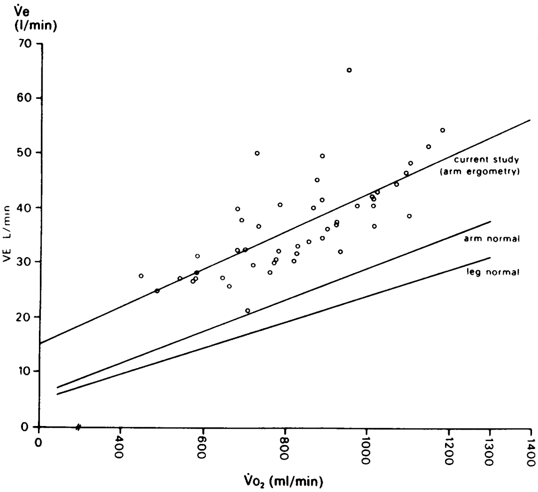

Fig 2 *Changes in ventilation ($\dot{V}e$) with increasing oxygen consumption ($\dot{V}o_2$) for all patients during arm ergometry, compared with normal values for the linear portion of the ventilatory response from published reports.*[11 12 19] *The regression equation for the predicted ventilatory response to leg exercise is $y = 0{\cdot}024 \times 0{\cdot}44$,*[12] *and for arm exercise is $y = +\,0{\cdot}029 \times -0{\cdot}02$.*[11 19] *The regression equation derived for the ventilatory response for our patients with chronic obstructive lung disease is $y = 0{\cdot}035 \times 8{\cdot}17$.*

associated with similar patterns of breathing in maximal and submaximal exercise.

In normal subjects the heart rate response at a given oxygen consumption is higher with arm work than with leg work, and the oxygen pulse is less at all levels of arm work. As oxygen pulse is in part dependent on stroke volume, it has been suggested that the decreased oxygen pulse seen in arm exercise is secondary to decreased venous return and the higher peripheral resistance that occurs during arm work.[18 19] Our patients also had a lower oxygen pulse during arm exercise than during leg exercise at both submaximal and maximal workloads. In addition, the maximum oxygen pulse for both forms of exercise in our patients was below normal.[20 21]

If arm ergometry is to be used as an alternative form of exercise testing, it would be important to compare the ventilatory responses of patients with chronic obstructive lung disease with the responses of normal individuals to arm exercise. Figure 2 compares the ventilatory responses of our patient group with normal ventilatory responses derived from the published studies on arm and leg ergometry. The ventilatory response in our patients with chronic obstructive lung disease is clearly abnormal at all levels of exercise, as would be expected from the increased dead space ventilation in these patients.

Exercise testing with the arms has been used little. This is somewhat surprising as use of the arms, and especially lifting and carrying, commonly leads to dyspnoea in patients with chronic obstructive lung disease. Our data suggest that exercise testing with the arms elicits maximum ventilation and heart rate responses similar to those produced by leg exercise testing. There are differences in submaximal cardiac and ventilatory responses but these can easily be accounted for by slight adjustments in the expected normal response during arm exercise. Arm ergometry is thus a suitable alternative method of exercise testing for patients with chronic obstructive lung disease who are unable to use a bicycle ergometer.

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