RESPIRATORY MEDICINE (2001) 95, 618–626
doi:10.1053/rmed.2001.1115, available online at http://www.idealibrary.com on IDEAL®

The body weight–walking distance product as related to lung function, anaerobic threshold and peak $\dot{V}O_2$ in COPD patients

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The product of walking distance and body weight (D·W) mimics the work of walking. We hypothesized the superiority of D·W to walking distance (D) alone in any correlation with lung function, anaerobic threshold (AT) and maximal oxygen uptake ($\dot{V}O_{2max}$). We further hypothesized that the D·W product for a 6-min walk test (6 MWT) would correlate with the AT and $\dot{V}O_{2max}$ because all three are markers of exercise ability.

Thirty-three male chronic obstructive pulmonary disease (COPD) patients with mean forced expiratory volume in 1 sec (FEV_1) of $1{\cdot}2 \pm 0{\cdot}4$ l (range 0·58–1·86 l) were enrolled. Six patients were excluded due to inability to achieve a maximal test. Lung function and self-assessed every-day activities using a oxygen–cost diagram were evaluated before entry of the study. A maximal effort ramp-pattern cardiopulmonary exercise test (CPET) and a 6 MWT were conducted in random order. Borg score, heart rate, and O_2 saturation with pulse oximetry (S_PO_2) were measured during both exercise tests. $\dot{V}O_2$ AT and minute ventilation were also measured during the CPET. Correlations were sought between the distance covered in the 6 MWT, and the D·W product with AT, $\dot{V}O_{2max}$ and other variables.

The average D and D·W were 456 m and 27·5 kg km^{-1}, respectively. D·W was superior to D alone when correlated with the $\dot{V}O_{2max}$ and AT determined from the CPET, while modestly correlated with the change (Δ) in Borg score and ΔS_pO_2 in the 6 MWT and self-assessed every-day activities. Distance × weight product was correlated with the AT and $\dot{V}O_{2max}$. In addition, D·W was better correlated with diffusing capacity for carbon monoxide and vital capacity than D alone.

We conclude that D·W mimics the work of walking better than D and is suggested as a parameter for evaluation of patients' fitness if gas exchange measurements are not available.

Key words: 6-min walking test; cycle ergometer; Borg score; oxygen–cost diagram; AT.

RESPIR. MED. (2001) 95, 618–626

Introduction

To quantify exercise fitness, a walking test measured as distance covered during a given period of time is commonly used. Previous reports used the covered distance to predict surgical outcome in the patients receiving lung resection (1,2); however, the results were inconsistent. Therefore, some investigators urged the use of the maximal exercise capacity as a better predictor of survival time when prioritizing patients for heart transplantation, while some used anaerobic threshold (AT) < 11 ml min^{-1}kg^{-1} as an indicator of major postoperative cardiac complications (3–6).

Because it is difficult to achieve a maximal exercise test in severely disabled patients, a sub-maximal exercise test, measured as the distance walked in 6 min (6 MWD) (D), has been found to be convenient, inexpensive and similar to daily activities. However, converting walking distance to maximal exercise capacity is not easily done because of differences in the characteristics of the exercise and the body weight factor confounding the walking performance.

The work of walking on a horizontal plane should correlate with horizontal work (W_{HO}) on a treadmill. The formula for $W_{HO} = K.m.V{\cdot}T{\cdot}\cos\theta$ (7). K is the work coefficient in kcal kg^{-1} km^{-1}; m, body mass; V, the walking velocity; T, the walking period; and θ, the angle of the treadmill incline. The angle of the incline is zero on level walking. K is nearly constant when walking speed is

Received 27 June 2000 and accepted in revised form 16 April 2001.
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0954-6111/00/070618+09 $35·00/0

250–600 m in 6 min. Therefore, the work of walking on the horizontal equals the product of distance and weight (D·W).

Lactic acidosis threshold or anaerobic threshold (AT) has been considered to be the maximal level of sustainable work capacity. The AT is usually 40–60% of the peak $\dot{V}O_2$ ($\dot{V}O_{2\ peak\ or\ max}$) in normal subjects. Therefore, the walking performance should be correlated significantly with the AT determined in a progressively increasing maximal effort exercise test. While a timed walk is a sustainable exercise for normal subjects, a walk test with verbal encouragement could be rather stressful for severely disabled patients. We hypothesize: (1) D·W correlates better with the AT, peak $\dot{V}O_2$ and maximal exercise capacity than D alone; (2) the walking performance is correlated with the AT and peak $\dot{V}O_2$ because the distance walked in 6 min is a measure of the level between sustainable exercise capacity and maximum exercise. To address these questions in COPD patients, we correlated the results of D and D·W product of the 6 MWT to Borg scale, daily activity symptoms, lung function, AT and peak $\dot{V}O_2$ during cycle ergometer exercise.

Materials and methods

SUBJECTS

Thirty-three males aged 50–76 (mean age $\pm$ SD $= 65 \pm 6$) years with chronic obstructive pulmonary disease (COPD) [forced expiratory volume in 1 sec (FEV_1) $< 1{\cdot}5$ l or $< 50\%$ predicted or $FEV_1\% < 65\%$] based on history, clinical findings and radiographic criteria were enrolled in the study. Their average weight was 60 ± 13 kg and height was 164 ± 6 cm. All subjects were clinically stable outpatients receiving a regular schedule of orally or inhaled administrated bronchodilators with or without oral prednisolone of less than 10 mg day^{-1}. Patients with significant arrhythmia or having a history of malignancy, cardiovascular or peripheral vascular disease, or locomotion problems were not included in the study. The procedures and the risks of the maximal exercise test were explained. The institutional review board approved this study and all subjects gave their consent to participate. Six patients were later excluded because they were unable to achieve a maximal exercise level, defined according to any one of the following criteria reached: (a) peak heart rate at peak exercise is 85% or more of the maximally predicted; (b) respiratory exchange ratio (RER) is 1·09 or more at the peak exercise; (c) arterial plasma bicarbonate at the peak exercise decreases from the resting baseline level by 4 mmol l^{-1} or more; (d) plasma pH value at the peak exercise is 7·35 or less (8). A total of 27 patients met these criteria and were retained in the study for analysis.

STUDY DESIGN

The following variables were measured: (a) self-assessed daily activities scored using an oxygen–cost diagram (OCD) (9); (b) pulmonary function testing (PFT); (c) 6 MWT; (d) increasing ramp-pattern cardiopulmonary exercise test (CPET) performed on a cycle ergometer to maximum. The walk test and the CPET were conducted in random order. We correlated the walking performance with the score of OCD, PFT, the AT and the peak $\dot{V}O_2$.

PROTOCOL AND MEASUREMENTS

Oxygen–cost diagram

OCD was used as a scale for daily activities assessed by patients themselves. Patients were asked to indicate a point on an OCD, a 100-mm long vertical line with every-day activities listed alongside the line, spaced according to the oxygen requirement associated with performing each task, above which they thought their breathlessness limited them (9). The distance from the zero point was measured and scored.

Pulmonary function testing

Neither cigarette smoking, coffee, tea, alcohol nor medications were permitted 24 h before any testing, nor could bronchodilators be administrated with a meter-dose inhaler within 3 h before testing. Pulmonary function tests were performed before the exercise tests. Maximally forced expired flow curves were performed on all patients using a mass flow sensor spirometer (6200 Autobox DL, SensorMedics, CA, U.S.A.). In all patients, the best of three technically satisfactory readings of FEV_1 and forced vital capacity (FVC) were reported. Total lung capacity (TLC), residual volume (RV) and vital capacity (VC) were measured with a pressure sensitive plethysmograph (6200 Autobox DL, Sensor Medics) and were shown at body temperature, ambient atmospheric pressure and fully saturated (BTPS). Single-breath transfer factor for carbon monoxide (D_1CO) was also measured. Simple volume calibration was conducted with a 3-l syringe before each test. The predicted values currently used in our institute are as follows: FEV_1 and FVC were race adjusted using 90% of the predicted equations established by Knudson *et al.* (10). The predicted TLC and D_LCO were 85% of the prediction equations from Goldman and Becklake (11) and Burrows *et al.* (12), respectively.

6-min walk test

The walk tests were conducted in a temperature-controlled corridor. Before and immediately after the walk test, systemic arterial blood pressure and respiratory frequency were measured. The perceived exertion was measured with a modified Borg score at rest, midway through and at the end of the walk. Patients were instructed to walk as far as possible with the help of verbal encouragement by an experienced investigator, as Guyatt *et al.* (13) recommended. Patients were allowed to stop to rest if needed. Oxyhaemoglobin saturation determined by pulse oximetry (S_pO_2) (Ohmeda 3760) and the heart rate readings were stored and later printed out as 15-sec averages. The absolute change in the heart rate in response to walk test was the difference between the baseline and the end. The change in S_PO_2 was the absolute change from the baseline to the nadir during the walk. Each patient performed two to three repetitions of walk tests separated by 2–4 h of rest. The highest distance walked in the 6 min (D) was recorded in meters. The distance was then converted to D·W by multiplying by the body weight in kilograms.

Maximal cardiopulmonary exercise test (CPET)

After revealing stable exercise gas exchange while the subject sat on the cycle ergometer (CardiO$_2$™, Medical Graphics, MN, U.S.A.), data were collected during a 2-min period of rest followed by a 2-min period of unloaded cycling, followed by a ramp-pattern cycle ergometer exercise test to exhaustion. The work rate was increased at a rate of 5–20 watts min^{-1} according to the subjects' fitness. The rate of increase was selected so the subjects were able to complete the test by approximately 10 min. During each test, a pedalling frequency of 60 rpm was maintained with the aid of a visual pedal rate indicator. $\dot{V}O_2$ (ml min^{-1}), $\dot{V}CO_2$ (ml min^{-1}) and minute ventilation ($\dot{V}E$, l min^{-1}) were computed breath by breath and the data were displayed every 15 sec using an on-line computer. We designated the $\dot{V}O_{2max}$ as peak or maximum $\dot{V}O_2$ that the patients achieved. Twelve-lead electrocardiography, heart rate and S_pO_2 using a pulse oximeter (Ohmeda 3740, BOC Health Care Company, CO, U.S.A.) were measured continuously. Calibrations of the preVent™ pneumotachograph were performed with a 3-l syringe before each test. The O_2 and CO_2 analysers were calibrated with standard gases.

Predicted maximum heart rate was calculated by using the following formula (14):

$$\text{Maximum heart rate} = 220 - \text{age} \quad (1)$$

To determine the maximal exercise on the basis of the criteria of change in HCO_3 and pH (Ciba-Corning 278 blood gas system) as claimed by Zavalal (8), arterial blood was sampled at rest and at the peak of exercise. In 24 patients, the pH value at peak exercise was less than 7·35; in 18 patients, the heart rate was $\geq 85\%$ predicted. In three patients only one of the four criteria was achieved; otherwise, $\geq$ two criteria were achieved. The AT was determined using modified *V*-slope method (15).

STATISTICAL ANALYSIS

Paired *t*-test was used when indicated. Pearson's correlation coefficient was used to determine (1) the relations between the walk performance (D or D·W) and the walking physiology (heart rate and S_pO_2 respiratory frequency and Borg score), the score of OCD, lung function; the AT and $\dot{V}O_{2max}$ (2) the relation of $\dot{V}O_{2max}$, and AT to the walk physiology. *P* value less than 0·05 was considered significant. The mean $\pm$ SD of each variable is shown. These procedures were carried out using an SAS software package and Microcal Origin version 4·0.

Results

THE SUBJECTIVE SYMPTOM AND PULMONARY FUNCTION TESTS

Table 1 shows the self-assessed daily activities and lung function of the patient group. Twenty-four (approximately 90%) of all patients had $FEV_1/VC < 65\%$, indicating most patients had moderate to severe airflow obstruction. The average score of OCD was 7·1, indicating that the subjects, on average, are able to walk uphill at a moderate pace or walk on the level briskly.

THE WALKING TEST AND THE MAXIMAL CARDIOPULMONARY EXERCISE TEST

Figure 1 shows the physiological changes in response to walk. Table 2 shows the average physiological changes. The mean heart rate increased immediately after the start of walk and reached a steady state by 2 min. The S_pO_2 decreased immediately after the start of walk and reached a nadir by 2 min. It then slightly recovered between 4 min and 6 min. This could be due to subjective self-adjustment of the pace. Table 3 shows the results of the maximal cardiopulmonary exercise test. In two of the patients the AT was indeterminate. The mean AT $\pm$ SD was $0{\cdot}72 \pm 0{\cdot}17$ l min^{-1} in the remaining 25 patients.

The heart rate, Borg score, and respiratory frequency were significantly higher for the maximal exercise test at the peak of exercise as compared to the walk test at the end of 6 min, respectively ($P < 0{\cdot}0001$, respectively). The S_pO_2 at the end of walk test was not different from that at the peak of CPET ($P > 0{\cdot}05$). The decrease in S_pO_2 in response to the ramp-pattern exercise test was also not different from the walk test. The heart rate, respiratory frequency, and Borg score in response to 6 MWT were significantly higher than at the AT in response to the CPET (all $P < 0{\cdot}05$) (see Tables 2 and 3). The results suggested that the walk test is a

TABLE 1. The subjective symptom and lung function ($n = 27$)

	Mean	SD
Score of OCD	7·1	1·3
VC (l)	2·8	0·5
FEV_1(l)	1·2	0·4
FEV_1 (%)	49	10
FEV_1/VC (%)	44	11
TLC (l)	6·2	0·8
FRC (l)	4·5	0·8
D_{LCO} (ml min^{-1} $mmHg^{-1}$)	16·6	5·9
D_{LCO} (%)	67	18

OCD = oxygen cost diagram.

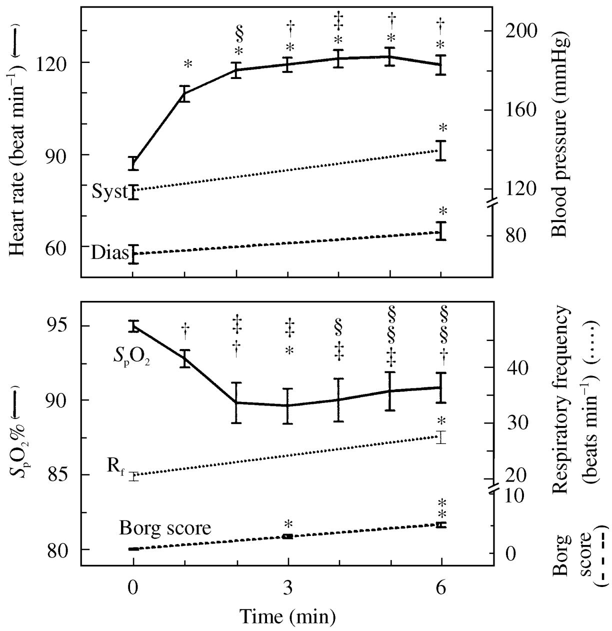

FIG. 1. Heart rate, blood pressure, respiratory frequency (R_f), oxyhaemoglobin saturation (S_pO_2) and Borg score in response to 6-min walk test. Data are averages for 27 subjects. SE (bars) and significant differences are provided at rest and at each min of exercise for heart rate and S_pO_2. SE and significant differences are provided at rest and at the end of walk for blood pressure and R_f. SE and significant differences are provided at rest, at 3 min, and at the end of walk for Borg score. Syst is systolic pressure, Dias is diastolic pressure; $*P<0{\cdot}0001$, $^{\dagger}<0.001$, $^{\ddagger}<0{\cdot}01$ $^{\S}P<0{\cdot}05$. In the upper panel, are comparisons of the heart rate and BP and in the lower panel are R_f are S_pO_2 in response to walk between at-rest and each minute during walk test.

sub-maximal exercise performance somewhere between the AT and a volitionally exhaustive ramp-pattern cycling exercise for most studied subjects.

TABLE 2. Physiological changes of the walking test (mean ± SD) ($n=27$)

	Start	End
Distance (M)	–	456 ± 84
Distance-weight product (kg km^{-1})	–	27·5 ± 8·5
Heart rate (beats min^{-1})	87 ± 11	119 ± 17*
Respiratory frequency (beats min^{-1})	20 ± 4	27 ± 6*
Blood pressure (mmHg)		
Systolic	118 ± 19	139 ± 26*
Diastolic	78 ± 11	88 ± 12*
Oxyhaemoglobin saturation (%)	95 ± 2	91 ± 5†
Borg score (0–10 range)	1 ± 1	5 ± 2*

Comparing the average at the start and at the end of walking $*P<0{\cdot}0001$, $^{\dagger}P<0{\cdot}001$.

COMPARISON OF D AND D·W IN RELATION TO SUBJECTIVE SYMPTOM, WALK PHYSIOLOGY AND PFT

The score of OCD weakly correlates with the D and D·W ($R^2=0{\cdot}16$, $P<0{\cdot}03$ and $R^2=0{\cdot}14$, $P<0{\cdot}05$, respectively) (Table 4) and $\dot{V}O_{2max}$ ($R^2=0{\cdot}14$, $P<0{\cdot}05$). The change in Borg score during the 6 MWT also weakly correlated with D and D·W ($R^2=0{\cdot}1$, $P=0{\cdot}09$ and $R^2=0{\cdot}15$, $P=0{\cdot}04$, respectively). The average S_pO_2 at rest was 95 ± 2% and the range of change in response to walk was 4 ± 5% (Table 2). The decrease in S_pO_2 did not correlate with D ($P=0{\cdot}6$) but correlated weakly with D·W ($P=0{\cdot}06$) (Table 4), suggesting O_2 desaturation contributed to the work of walking rather than the walking distance alone. The change in heart rate was positively correlated with both D and D·W ($P<0{\cdot}01$). Lung function such as VC, FEV_1 and D_{LCO} weakly correlated with the D ($P=0{\cdot}08-0{\cdot}1$) (Table 4). The TLC and FRC were independent of the D. The correlation between D_{LCO} and VC with the walk performance can be enhanced by converting the D to D·W ($P=0{\cdot}02$ and 0·0001, respectively). Again, the TLC and FRC were independent of D·W.

TABLE 3. Physiological changes of the maximal cardiopulmonary exercise test (mean ± SD) ($n=27$)

	Rest	AT	Peak
$\dot{V}O_2$ (l min^{-1})	0·25 ± 0·04	0·72 ± 0·17	1·11 ± 0·35
Heart rate (beat min^{-1})	81 ± 13	106 ± 14	139 ± 17
$\dot{V}E$ (l min^{-1})	10·8 ± 1·9	24·6 ± 4·1	39·8 ± 11·1
Respiratory frequency (beats min^{-1}) at rest	20 ± 6	25 ± 5	34 ± 7
Oxyheamoglobin saturation, (%) at rest	96 ± 2	95 ± 3	92 ± 3
Borg score (0–10 range) at rest	0 ± 0	3 ± 2	8 ± 2

Repeatedly comparing the average at rest, at the anaerobic threshold (AT) and at the peak of maximal cycling test. All $P<0{\cdot}0001$.

TABLE 4. Comparison of the walking distance and distance-weight product in relation to self-assessed symptom, walk physiology, lung function, and exercise aerobic capacity

	Walking distance		Distance-weight	
	r	*P*-value	*r*	*P*-value
Score of OCD	0·40	0·03	0·37	0·05
Physiology of walking				
Δ Heart rate	0·51	0·005	0·49	0·008
Δ Respiratory rate	0·02	NS	0·13	NS
Δ S_pO_2	0·10	NS	0·37	0·06
Δ Borg score	0·32	0·09	0·39	0·04
D_{LCO}	0·35	0·08	0·70	0·0001
D_{LCO}%	0·35	0·08	0·53	0·006
VC (l)	0·34	0·08	0·45	0·02
FEV_1(l)	0·31	0·1	0·36	0·06
TLC (l)	0·22	NS	0·27	NS
AT	0·36	0·07	0·71	<0·0001
$\dot{V}O_{2\ max}$	0·4	0·02	0·67	0·0001

OCD: oxygen-cost diagram, Δ: absolute changes of variables from baseline to the end of the 6th min; S_pO_2: oxyhaemoglobin saturation measured by a pulse oximeter; AT = anaerobic threshold.

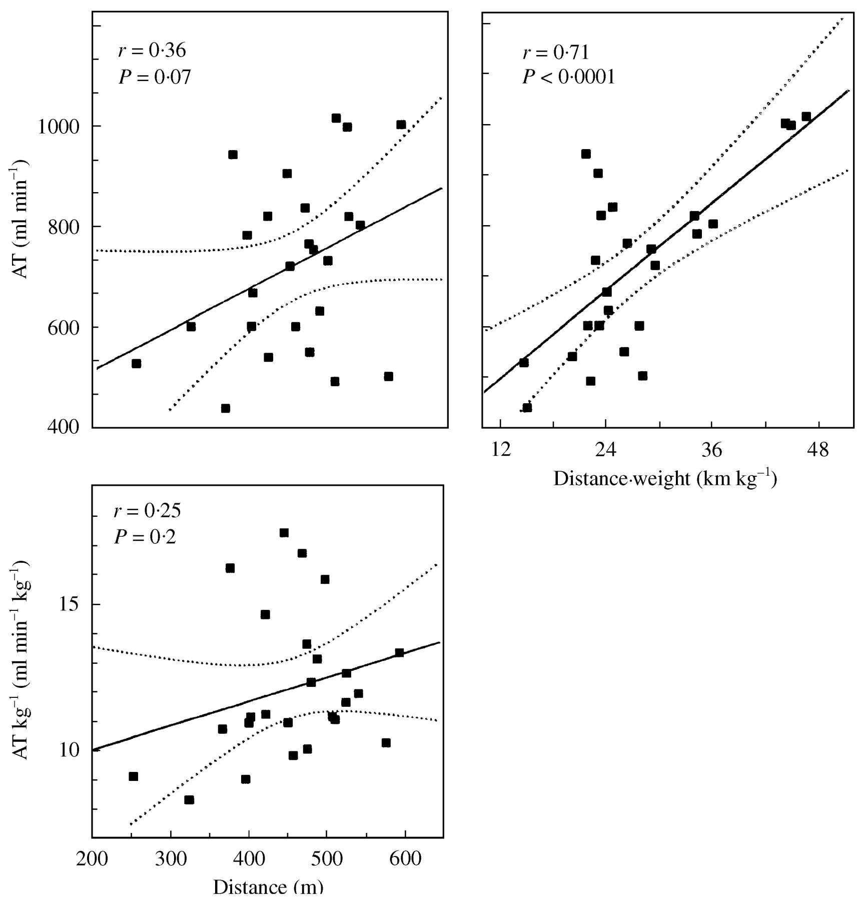

FIG. 2. Anaerobic threshold (AT) and AT normalized to body weight (kg) measured during a maximal cycling test as a function of distance measured during a 6-min walk test for the left panels. Each point in a panel represents a different subject. Solid lines are the best least square fit correlation between AT or AT kg^{-1} and distance. The curve lines are the 95% CI lines. The distance is then converted to the product of distance and body weight. The correlation between AT and D·W is shown on the right panel.

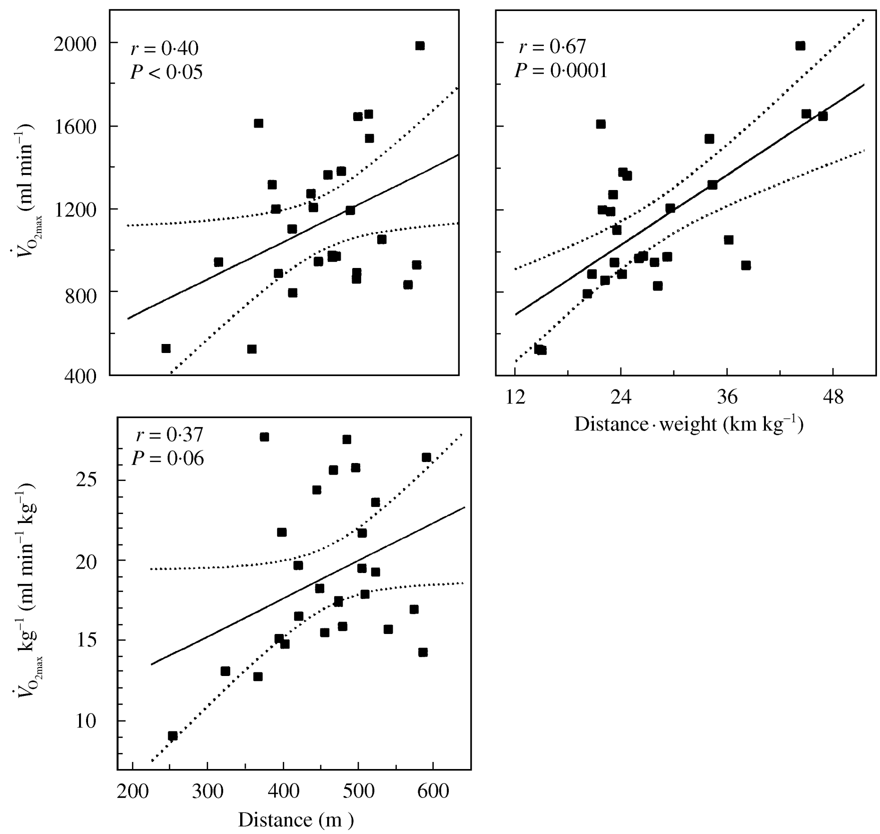

FIG. 3. Maximal oxygen uptake ($\dot{V}O_{2max}$) and $\dot{V}O_{2max}$ normalized to body weight (kg) measured during a maximal cycling test as a function of distance measured during a 6-min walk test for the left panels. Each point in a panel represents a different subject. Solid lines are the best least square fit correlation between $\dot{V}O_{2max}$ or $\dot{V}O_{2max}\,kg^{-1}$ w and distance. The curve lines are the 95% CI lines. The distance is then converted to the product of distance and body weight. The correlation between $\dot{V}O_{2max}$ and D·W is shown on the right panel.

COMPARISON OF D AND D·W IN RELATION TO THE AT AND $\dot{V}O_{2MAX}$

The correlation between D alone and the AT was weak ($R^2=0{\cdot}13$, $P=0{\cdot}07$) (Fig. 2). The correlation was much improved when AT was correlated with D·W ($R^2=0{\cdot}5$, $P<0{\cdot}0001$) (Fig. 2 and Table 4). The correlation between D and $\dot{V}O_{2max}$ was also much improved if D was converted to D·W ($R^2=0{\cdot}16$ *vs.* 0·45, $P<0{\cdot}05$ *vs.* $=0{\cdot}0001$) (Fig. 3). The D·W is correlated with the AT and $\dot{V}O_{2max}$ ($R^2=0{\cdot}5$ *vs.* 0·45) (Figs. 2 and 3).

COMPARISON OF WALKING PHYSIOLOGY IN RELATION TO THE AT AND $\dot{V}O_{2MAX}$

The correlation between the changes in heart rate, respiratory frequency, S_pO_2 and Borg score in response to walking with the AT, normalized to the body weight, is slightly superior to the correlation with $\dot{V}O_{2max}$ normalized to body weight, but neither was significant at the 0·05 level ($r=0{\cdot}25-0{\cdot}32$, $P=0{\cdot}1-0{\cdot}2$ *vs.* $r=0{\cdot}05-0{\cdot}1$, $P=0{\cdot}3-0{\cdot}8$). This indicated that walking physiology can not be extrapolated to the AT and $\dot{V}O_{2max}$ derived from a maximum exercise. The S_pO_2 (absolute value but not the change in S_pO_2), in response to walk at the 6 min, significantly negatively correlated with the AT kg^{-1}($r=-0{\cdot}44$, $P=0{\cdot}04$). This indicated that the more the fitness, the lower the oxyhaemoglobin desaturation in response to the walk.

Discussion

6-MIN WALKING TEST

That a 6-min walking test is a sub-maximal exercise test is supported by (l) the steady-state heart rate response being reached by 2 min after the start of walk, analogous to CWR exercise below the AT (16); (2) a constant distance covered every 2 min during a 12 MWT (17); (3) a similar correlation between the AT and $\dot{V}O_{2max}$ with walking performance (Figs. 2 and 3); (4) changes in heart rate, respiratory frequency and Borg score in response to walking were estimated to be ~50–60% of the changes in these variables in response to maximal exercise; (5) a steady-state for $\dot{V}E$

and $\dot{V}O_{2max}$ is reached within 6 min (18). While the $\dot{V}E$, $\dot{V}O_{2max}$ heart rate and the distance covered in response to walk were analogous to CWR exercise, the Borg score increased along with the duration of exercise, which is consistent with a previous report (17). The increase in heart rate in response to walking and the more the fitness, the lower the absolute S_pO_2 at the 6th min of walking, suggests that our patients walked as far as they could under the influence of verbal encouragement, as previously reported (13).

The oxyhaemoglobin saturation decreased soon after the start of exercise and reached a nadir by 2 min. Oxyhaemoglobin saturation slightly but significantly increased after 4 min, suggesting a slowing in walking pace. It is supported by the mean distances walked during 3–4 min and 5–6 min being lower compared to the distance walked during 1–2 min during a 6 MWT under verbal encouragement (13). A decrease of S_pO_2 in response to walking by 2–3 min in COPD patients was also reported by Spence *et al.* (19). However, oxyhaemoglobin resaturation after the nadir did not occur in their report. The pattern of oxyhaemoglobin desaturation in response to walking was analogous to maximal exercise in COPD patients (14); also, the magnitude of oxyhaemoglobin desaturation was not significantly different between the sub-maximal and maximal tests.

COMPARISON OF D AND D·W IN RELATION TO SUBJECTIVE SYMPTOM, WALK PHYSIOLOGY AND PFT

The oxygen–cost diagram is oxygen requirement associated with performing each task, above which the subjects thought their breathlessness limited them. Therefore, the score of OCD is expected to significantly correlate with the maximal exercise. It also significantly correlates with the sub-maximal exercise test such as walking distance and D·W in this study. However, it has been reported that the cognition of breathlessness during exertion (e.g. using the Borg score) is inconsistent. Some investigators reported the cognition of breathlessness during exertion is individual (20,21) and highly variable in sub-maximal exercise (22) while some reported to be better related to a walking test than to a maximal exercise test (23). Our study showed that the change in Borg score in response to walking weakly correlated with the D·W and even less well with D (Table 4).

The correlation between the change in heart rate in response to walking and the D remained significant if the D was converted to D·W (see Table 4). The correlation between the D·W and change (Δ) in S_pO_2 in response to walking is much better than the correlation between D and Δ S_pO_2. In turn, the D·W is not just a product but a variable of the work of walking. Mak *et al.* reported no relation between mean S_pO_2 and walk distance (23), as in our study. However, the correlation between mean S_pO_2 and walk distance was improved if the D was converted to D·W in this study.

Previous studies showed FVC, FEV_1 and D_{LCO} are correlated with walking distance in the patients with airflow obstruction (9,23,24). These variables weakly predict the D in this study, however, D_{LCO} is well correlated with D·W. While D_{LCO} is well correlated with D·W and D·W is well correlated with AT, Δ S_pO_2 and absolute S_pO_2 at the 6th min of walking are weakly correlated with D·W and AT kg^{-1}, respectively. This can be extrapolated to the report of Sue *et al.* that D_{LCO} at rest is not necessarily a predictor of abnormal gas exchange during exercise for shipyard workers (25).

COMPARISON OF D AND D·W IN RELATION TO THE AT AND $\dot{V}O_{2MAX}$

Since the work of walking equals the D·W product, the correlation between the AT and $\dot{V}O_{2max}$ with D·W might be expected to be superior to the correlation between the AT and $\dot{V}O_{2max}$ with the D, as experimentally found (Table 4). However, the correlations between the AT and $\dot{V}O_{2max}$ with walk performance are similar. It has been suggested that maximum $\dot{V}O_2$ (ml kg^{-1} min^{-1}) be used to assess disability (26). The correlation between walking distance and $\dot{V}O_{2max}$ (ml kg^{-1} min^{-1}), normalized to weight, should be expected to be the same as the correlation between the distance-weight product and $\dot{V}O_{2max}$ (ml min^{-1}). In fact, the relationship between the distance-weight product and $\dot{V}O_{2max}$ (ml min^{-1}) ($r=0{\cdot}67$, $P=0{\cdot}0001$) is more significant than the relationship between the walk distance and $\dot{V}O_{2max}$ normalized to weight ($r=0{\cdot}37$, $P=0{\cdot}06$). D·W is analogous to the work of walking that can be performed and correlated similarly with the AT and $\dot{V}O_{2max}$. More than 80% of increase in $\dot{V}O_2$ in response to cycle ergometer is generated by leg muscle, which takes merely ~25% of the whole body weight (27), while most of the increase in $\dot{V}O_2$ in response to walking is generated by moving the whole body weight. Previous studies also reported that walking is more work for a person of greater girth and hence a distance walked is not necessarily interchangeable in its significance with cycle ergometry (17,28).

LIMITATIONS OF THE STUDY

The criteria employed here for a maximum exercise level achieved by the patients with COPD could be arbitrary. A pH less than 7·35 is recommended as a general guide for a maximum exercise level but may not be appropriate for COPD patients. In 24 of 27 patients more than two of the four criteria were achieved at the peak of exercise. In three patients only one criteria was achieved; the heart rate >85% predicted in one, the RER >1·09 in one, and the pH = 7·3 at the peak in the third.

The methods to measure the AT have been reported with non-invasive gas exchange methods and invasive blood measurement methods. Three identifiable thresholds (lactic acidosis threshold by measure of changes in standard bicarbonate, lactate threshold by measure of changes in blood lactate and gas exchange threshold by using modified

V-slope method) are related to the onset of anaerobic metabolism (29). The physiologic reasons that these three thresholds do not occur at precisely the same point have been elucidated.

Conclusions

The product of distance and body weight (D·W) is superior to walking distance (D) alone in correlating with change in oxyheamoglobin desaturation during walking, D_LCO, the AT and $\dot{V}O_{2max}$. The likely reason is that D·W reflects the work of walking better than D. Walking performance is correlated with the AT and $\dot{V}O_{2max}$, likely because walking is a level of exercise between AT and maximum for patients with moderate to severe COPD. We suggest using D·W rather than D for evaluation of exercise tolerance using the 6 MWT, if a cardiopulmonary exercise testing laboratory is not available.

Acknowledgements

This study was supported in part by the Chang Gung Medical Research Program (CMRP #443).

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