Cardiorespiratory Responses during Cycle Ergometer Exercise with Different Ramp Slope Increments in Patients with Chronic Obstructive Pulmonary Disease

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Abstract

Objective The ramp exercise test has been widely used to evaluate cardiopulmonary responses to an incremental exercise load. This study was performed to clarify whether different slopes of the ramp exercise test influence exercise tolerance, exercise limiting factors, and respiratory pattern in patients with chronic obstructive pulmonary disease (COPD).

Subjects and Methods We applied three different slopes (5 W/min, 10 W/min and 20 W/min) of the ramp exercise test in 9 patients with COPD and evaluated cardiopulmonary responses.

Results There were no significant differences in peak oxygen uptake, anaerobic threshold (AT), minute ventilation, heart rate, arterial oxygen saturation, expired tidal volume, or respiratory rate at the maximal load among the three different ramp exercises tested. AT could be determined in six of nine patients (67%) at the slope of 5 W/min, in 8/9 (89%) at the slope of 10 W/min, and in 9/9 (100%) at the slope of 20 W/min.

Conclusion The findings suggest that the ramp slope does not affect exercise tolerance, exercise limiting factors, or respiratory patterns and each of these ramp slopes is useful for the evaluation of COPD. Ramp slopes of 10 W/min or 20 W/min should be appropriate for the determination of AT.

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Key words: incremental exercise test, anaerobic threshold

Introduction

The ramp exercise test is an incremental exercise test in

which the exercise load is increased continuously and linearly (1). This test has been widely used for clinical purposes in recent years, because it can be used to determine both the maximal oxygen uptake ($\dot{V}O_2$ max) and the maximal minute ventilation ($\dot{V}E$ max) for a short period of time. This test may also be used for the determination of anaerobic threshold (AT) based on respiratory gas analysis (2).

For patients with chronic obstructive pulmonary disease (COPD) showing reduced exercise tolerance, the setting of a relatively small load such as 10 W/min or 20 W/min (3, 4) in the ramp exercise test has been reported. However, a standard method for incremental exercise has not yet been established in these patients. A major factor causing exercise limitation for COPD patients is reduced pulmonary function, and other factors include deconditioning, cardiac factors and symptomatic dyspnea (5, 6). The respiratory pattern in COPD patients may vary from rapid and shallow to deep and slow (7, 8). It is not known whether ramp slope during exercise testing influences exercise tolerance, exercise limiting factors, or respiratory pattern in COPD patients, or which slope is the most appropriate for testing patients with COPD. In the present study, we employed three different slopes (5 W/min, 10 W/min and 20 W/min) for the ramp exercise test to help clarify these issues.

Subjects and Methods

Subjects

We studied nine patients with stable COPD. The diagnosis of COPD was made using the standards of the American Thoracic Society (9). The study patients were selected based on the presence of a forced expiratory volume in 1 sec ($FEV_{1.0}$) less than 70% predicted, $FEV_{1.0}$ /forced vital capacity (FVC) ratio less than 70%, residual volume (RV)/total lung capacity (TLC) ratio more than 45%, and emphysematous changes seen on chest computed tomography scanning. Patients who had a

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Table 1. Anthropometric and Pulmonary Function Data in Nine Patients with Chronic Obstructive Pulmonary Disease

Patient No.	Sex	Age	Height (cm)	Weight (kg)	FVC (l)	FEV _{1.0} (l)	FEV _{1.0} /FVC (%)	%FEV _{1.0} (%)	DLCO (ml/m/mmHg)	RV/TLC (%)
1	F	72	153.2	41.0	1.51	0.55	36.4	34.2	11.7	56.2
2	M	64	163.0	52.0	3.41	0.80	23.5	32.0	16.0	49.5
3	M	76	165.0	45.0	2.03	0.65	32.0	30.0	10.1	64.4
4	M	68	166.5	44.0	2.49	1.52	61.0	61.3	19.3	50.2
5	M	76	161.0	46.0	2.00	0.87	43.5	42.9	4.9	66.4
6	M	65	159.0	52.0	1.87	0.74	39.6	28.9	7.7	57.7
7	M	69	164.0	45.0	3.11	0.98	31.5	41.0	6.4	53.5
8	M	72	165.0	63.5	2.56	0.95	37.1	41.3	12.2	50.6
9	M	78	170.0	54.0	2.18	0.81	37.2	35.7	9.2	57.8
Mean		71.1	163.0	49.2	2.35	0.87	38.0	38.6	10.8	56.3
S.D.		5.0	4.8	6.9	0.61	0.28	10.3	9.9	4.6	6.1

FVC: forced vital capacity, FEV_{1.0}: forced expiratory volume in 1 second, FEV_{1.0}/FVC: ratio of forced expiratory volume in 1 second to forced vital capacity, %FEV_{1.0}: % of predicted forced expiratory volume in 1 second, DLCO: diffusing capacity, carbon monoxide, single-breath method, RV/TLC: ratio of residual volume to total lung capacity.

history of right heart failure, resting PO₂ less than 60 torr, or ischemic heart failure were excluded from the study. Patient characteristics are shown in Table 1.

Pulmonary function tests

Pulmonary function tests were performed using a rolling seal spirometer (Chestac-55V, CHEST, Tokyo). The complete study was performed 1 to 14 days prior to the exercise test. Lung volumes were determined by the He dilution method and single breath diffusing capacity was measured with a single breath diffusion technique. The predicted normal values for FEV_{1.0} were determined according to the method of Berglund et al (10).

Exercise tests

Exercise tests were performed on an electromagnetically braked cycle ergometer under continuous ECG, blood pressure, and arterial oxygen saturation (SaO₂) (using a pulse oximeter, PULSOX-7, Minolta) monitoring. Informed consent was obtained from all patients. Each subject repeated the ramp exercise test 3 times on 3 separate days within a 10-day period. Slopes for the ramp test were set at 5, 10 and 20 W/min. The order for administering the three ramp slopes was randomized. This ergometric equipment (Aerobike 232CLX, Combi) was designed to control both power and torque, regardless of the pedaling frequency, using a feed back control system. Following the warm-up exercise consisting of 2 minutes pedaling at 10 W, the ramp exercise was started at a pedaling frequency of 60 rpm. The exercise intensity increment was continued until the subject could no longer maintain a pedaling frequency of 60 rpm.

Immediately after the completion of the test, patients were asked why they stopped the test and were requested to estimate the intensity of dyspnea and leg effort. The symptoms of

the highest intensity were identified as the exercise limiting symptoms.

Respiratory gas and data analysis

Respiratory gas analysis was performed throughout the exercise test using a respiratory gas analysis system (Aero Monitor AE-280, Minato Medical Science, Osaka) consisting of a zirconia oxygen analyzer, an infrared carbon dioxide analyzer, and a hot wire spirometer. The system was carefully calibrated before each test. Oxygen uptake ($\dot{V}O_2$), CO₂ output ($\dot{V}CO_2$), expired tidal volume (TV), dead space volume/tidal volume (VT/VD) ratio, and respiratory rate were measured on a breath-by-breath basis. Derived parameters such as minute ventilation ($\dot{V}E$), $\dot{V}E/\dot{V}CO_2$, $\dot{V}E/\dot{V}O_2$, respiratory exchange ratio (R; $\dot{V}CO_2/\dot{V}O_2$), end-tidal O₂, and end-tidal CO₂ were calculated simultaneously and displayed with the heart rate and $\dot{V}O_2$ on a computer (PC-9801, NEC, Tokyo) during the gas analysis.

The peak $\dot{V}O_2$ was defined as the average of $\dot{V}O_2$ values over the last 15 seconds of each testing level. Anaerobic threshold (AT) was determined from gas exchange data by the V-slope method (2) using our software, which determines the turning point of the $\dot{V}O_2$ - $\dot{V}CO_2$ relationship curve by two linear regression lines. The ratio of the increase in $\dot{V}O_2$ to increase in work rate (work efficiency: $\Delta\dot{V}O_2/\Delta WR$) also was determined by linear regression of $\dot{V}O_2$ plots from 1 minute after the start of ramping up to the point of the maximal load, using our software.

Statistical analysis

Statistical analysis was performed using StatView-J4.11 software and data are presented as the mean $\pm$ SD. Repeated-measures analysis of variance (Repeated-measures ANOVA) was used to evaluate possible differences in the values for the aerobic parameters and other variables due to variations in the

ramp slope. The Fisher's protected least significant difference was used to isolate the mean value contributing to any significant F ratios. Differences were considered significant at $p < 0.05$.

Results

Table 2 shows changes in the peak $\dot{V}O_2$ at three different slopes of the ramp exercise tests. There was no significant difference in the peak $\dot{V}O_2$ among the three ramp slopes in the study patients.

Table 3 shows the values for each aerobic function obtained at the three different slopes studied in our nine patients. There were no significant differences in the values of ventilation, heart rate, and SaO_2 at the maximal point of the exercise among the three ramp slopes tested. Exercise at all ramp slopes produced to the same values for tidal volume, respiratory rate, and VD/VT ratio at the maximal load. The exercise limiting symptoms included dyspnea in seven patients and leg effort in two pa-

tients. These pattern and frequency of these symptoms was unchanged by the ramp slopes used.

AT values determined by the V-slope method are shown in Table 4. AT values were determined in six of nine patients (67%) at a slope of 5 W/min, in 8/9 (89%) at a slope of 10 W/min, and in 9/9 (100%) at a slope of 20 W/min. AT values were not significantly different between exercise at a slope of 5 W/min, 10 W/min, and 20 W/min in five patients (patients 1, 3, 4, 6 and 9, Table 4).

Table 5 shows the maximal work rate (WR max), working efficiency ($\Delta\dot{V}O_2/\Delta WR$) and performance time at each ramp slope. WR max values were increased progressively with increasing ramp slope, and differences in these values were significant among the three different ramp slopes tested. The $\Delta\dot{V}O_2/\Delta WR$ and performance time decreased as the ramp slope increased, and differences in these values were significant among the three different slopes tested.

Table 2. Peak $\dot{V}O_2$ Values at Different Slopes of the Ramp Exercise Test

Patient No.	Peak $\dot{V}O_2$ (ml/min) at a ramp slope of:		
	5 W/min	10 W/min	20 W/min
1	538	471	480
2	760	734	794
3	572	536	532
4	447	449	413
5	676	689	659
6	556	527	618
7	542	560	523
8	779	743	814
9	533	536	517
Mean	600.3	582.8	594.4
S.D.	112.5	110.8	138.6

Peak $\dot{V}O_2$ peak oxygen uptake.

Table 4. Anaerobic Thresholds Determined Using the V-slope Method

Patient	AT (ml/min) at a ramp slope of:		
	5 W/min	10 W/min	20 W/min
1	420	408	410
2	ND*	533	626
3	545	441	455
4	425	391	397
5	651	ND	614
6	556	510	540
7	ND	429	434
8	ND	557	543
9	406	431	411

AT: anaerobic threshold, *Not determined because of technical problem.

Table 3. Maximum Values of Aerobic Function on Ramp Exercise Testing

	Ramp slope		
	5 W/min	10 W/min	20 W/min
$\dot{V}E$ (l/min)	27.5 $\pm$ 4.1	26.9 $\pm$ 5.0	27.8 $\pm$ 4.3
SaO_2 (%)	90.2 $\pm$ 4.3	89.0 $\pm$ 5.2	90.7 $\pm$ 4.1
Heart rate (beats/min)	115.8 $\pm$ 14.4	113.0 $\pm$ 17.2	117.9 $\pm$ 15.3
Respiratory rate (breaths/min)	24.8 $\pm$ 4.2	24.7 $\pm$ 4.4	24.6 $\pm$ 4.2
Expired tidal volume (ml)	1,183.8 $\pm$ 140.7	1,173.6 $\pm$ 249.7	1,214.3 $\pm$ 204.9
VD/VT	0.43 $\pm$ 0.05	0.44 $\pm$ 0.05	0.43 $\pm$ 0.05

$\dot{V}E$: minute ventilation, SaO_2 : arterial oxygen saturation, VD/VT: ratio dead space volume to tidal volume.

Each value represents the mean $\pm$ standard deviation in nine patients studied.

Table 5. Comparison of WR max, Work efficiency ($\Delta\dot{V}O_2/\Delta WR$) and Performance Time at Different Ramp Slopes

	Ramp slope		
	5 W/min	10 W/min	20 W/min
WR max (W)	43.2±8.1	55.0±11.0	71.0±15.7
$\Delta\dot{V}O_2/\Delta WR$ (ml/min/W)	7.38±2.04	5.04±1.42	3.44±1.12
Performance time (sec)	440.0±53.9	302.2±40.2	196.7±41.5

*p<0.05, **p<0.01, ***p<0.0001, WR max: maximal work rate.

Discussion

The ramp exercise test is useful for measuring $\dot{V}O_2$ max, widely used as an indicator of exercise tolerance. This method is based on the application of a single load in a short period of time (1), and therefore the test has been introduced for evaluating exercise tolerance in both healthy and COPD patients. Reduced ventilatory reserve due to obstructive dysfunction is an exercise limiting factor for most patients with COPD. In some COPD patients, other exercise limiting factors include deconditioning, cardiac factors, and symptomatic dyspnea. These exercise limiting factors associated with COPD also are evaluable by the ramp exercise test. The respiratory pattern in COPD patients shows variation such as a rapid and shallow or deep and slow type. In the present study, we investigated the effects of three different ramp slopes on exercise tolerance, exercise limiting factors, and a respiratory pattern in COPD patients.

Cardiorespiratory responses to different loads on the ramp exercise test have been reported to be similar among healthy subjects when $\dot{V}O_2$ max and AT values were examined by applying different loads during the test (11). In COPD patients with low exercise tolerance, however, prolonged exercise at a gentle slope of the ramp may cause leg fatigue, which may have a significant exercise limiting effect and decreased exercise tolerance. In contrast, our data indicate that there was no difference in peak $\dot{V}O_2$ and AT values, as indicators of exercise tolerance, or in $\dot{V}E$, SAO_2 , heart rate, or exercise limiting symptoms at the three different slopes tested. We also found no difference in the respiratory rate or expired tidal volume at the maximum exercise at the different ramp slopes tested. Respiratory pattern at the maximal load, which is determined by respiratory rate and expired tidal volume, was also not affected by the slope of the ramp exercise test.

The AT has been widely measured as an indicator of exer-

cise tolerance for clinical evaluation (12). The V-slope method has been reported to be useful for evaluating AT in COPD patients based on respiratory gas analysis (13). This method is based on changes in $\dot{V}O_2$ and $\dot{V}CO_2$, both of which may be measured non-invasively. Using this method, however, it is difficult to determine the AT in some subjects because of difficulty determining the turning point of $\dot{V}O_2$ - $\dot{V}CO_2$ curve due to an excess of $\dot{V}CO_2$ caused by lactate accumulation, or because of failure to reach the AT at the maximum exercise (13). Our data show that AT was not successfully determined in one-third of the patients when the ramp slope of 5 W/min was applied. This is probably due to moderate changes in $\dot{V}O_2$ and $\dot{V}CO_2$ leading to difficulty in determining the threshold when the ramp slope is modest and the performance time is long. Therefore, 10 W/min or 20 W/min appears to be an appropriate ramp slope for the determination of AT in COPD patients.

The work rate at the maximum exercise increased significantly, while work efficiency decreased as the ramp slope was increased. Similar results have been reported in healthy subjects (14, 15). The reason for these observations is that the difference in the actual exercise load from metabolic function subsequently induced by the exercise becomes greater as the ramp slope becomes steeper (14). In the present study, considerable differences were observed in the maximal work rate values at slopes of 5 W/min versus 20 W/min. Accordingly, it is necessary to be careful about the condition how the ramp exercise test is set up when WR max is used as an indicator of exercise tolerance or when it is used as a criteria for prescribing a exercise therapy.

A slope of 20 W/min produced extremely short performance times of about 3 minutes. To evaluate parameters such as Borg scale scores at each minute during exercise (16), an appropriate performance of 5 to 10 minutes is necessary. Selection of a ramp slope which will allow appropriate performance time is difficult in COPD. Our data suggest that few patients reach an appropriate performance time at a slope of 20 W/min. Therefore, to evaluate these parameters at each minute during exercise testing, a slope of 5 W/min or 10 W/min should be used for the ramp exercise test.

In conclusion, our data suggest that differences in ramp slope do not affect peak $\dot{V}O_2$ or AT values, exercise limiting factors, or respiratory patterns in COPD patients and therefore, each ramp slope may be appropriate for the evaluation of a COPD patient. A slope of 10 W/min or 20 W/min should probably be used for determination of AT using the V-slope method in COPD patients. To evaluate parameters which need to be monitored at 1 minute intervals, a slope of 5 W/min or 10 W/min appears useful. Therefore, the most useful single slope is 10 W/min for ramp exercise testing of COPD patients.

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