

# Comparison of Different Exercise Tests in Assessing Outcomes of Pulmonary Rehabilitation

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**INTRODUCTION:** Common modalities of clinical exercise testing for outcome measurement after pulmonary rehabilitation (PR) include walk tests, progressive cycle ergometry, and cycle endurance testing. We hypothesized that patients' responses to PR, as measured by those 3 tests, are differentially correlated, and we designed a study to investigate the tests' capacity to detect changes after PR. **METHODS:** We prospectively tested 37 male patients with stable chronic obstructive pulmonary disease who completed a comprehensive 6-week PR program that included supervised exercise training that emphasized steady-state lower-limb aerobic exercise. Before and after the PR program the patients underwent 6-minute walk test, progressive cycle ergometry, and cycle endurance testing (at 80% of the peak work rate achieved during progressive cycle ergometry). The exercise performance indices of interest were the peak oxygen uptake ( $\dot{V}_{O_{2,max}}$ ) and maximum work-rate ( $W_{max}$ ) during progressive cycle ergometry, the cycling endurance time, and the 6-minute walk distance (6MWD). **RESULTS:** After PR there were statistically significant improvements in 6MWD (16%,  $p < 0.001$ ),  $\dot{V}_{O_{2,max}}$  (53%,  $p = 0.004$ ),  $W_{max}$  (30%,  $p = 0.001$ ), and cycling endurance time (144%,  $p < 0.001$ ). The changes in  $\dot{V}_{O_{2,max}}$  and  $W_{max}$  were significantly correlated ( $r = 0.362$ ,  $p = 0.027$ ), as were the changes in endurance time and  $W_{max}$  ( $r = 0.406$ ,  $p = 0.013$ ). There was no significant correlation between changes in any other exercise index. **CONCLUSIONS:** Among the frequently used exercise tests in PR, the most responsive index is the endurance time. The correlation between the post-PR changes in the various exercise indices is poor. *Key words:* exercise capacity, chronic obstructive pulmonary disease, walk test, ergometry, cycling test, endurance. [Respir Care 2004;49(12):1498–1503. © 2004 Daedalus Enterprises]

## Introduction

Pulmonary rehabilitation (PR) is a multidisciplinary program of care for patients with chronic respiratory impairment. PR is individually tailored and designed to optimize the patient's physical and social performance and autonomy.<sup>1</sup> Among the various components of PR, there is compelling evidence that exercise training is most effective in improving the functional capacity of patients with chronic respiratory disease, in particular, chronic obstructive pulmonary disease (COPD).<sup>2</sup>

To determine individual patient responses and evaluate the overall effectiveness of a PR program, outcome assessment is essential.<sup>1</sup> Measures that assess functional outcomes after PR include subjective symptom and health status questionnaires and various types of exercise testing.<sup>3</sup> Exercise testing is particularly appealing for this purpose as, in contrast to most symptom and health status surveys, it provides objective data using a continuum of severity rather than a finite number of categories and exhibits less intra-subject variability than the subjective questionnaires.<sup>4</sup>

Common modalities of clinical exercise testing for outcome measurement in PR include the walk test, progressive cycle ergometry, and the cycle endurance test. Though the relationship<sup>5</sup> and the reproducibility<sup>6</sup> of the measures of exercise performance of those 3 tests with patients with COPD have been studied, no study has specifically and simultaneously compared the responsiveness of these most frequently used measurements of exercise performance af-

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ter PR. An effective PR program usually improves exercise endurance but has little or no effect on maximum exercise capacity.<sup>7</sup> Recently, Oga et al<sup>5</sup> found that the exercise capacity measured by each of these tests correlated significantly to pulmonary function, dyspnea, and health-related quality of life among patients with COPD, but some differences in the aspects they evaluated were found. For instance, the study<sup>7</sup> suggested that walking tests may be a better measure of daily activities than cycling. The cycling endurance time might also be a different index from the other conventional measures of exercise capacity, with high sensitivity for detecting changes such as improvement in exercise performance after bronchodilators.<sup>8,9</sup> For those reasons, we hypothesized that the responses to PR, as measured by the various clinical exercise tests, might be differentially correlated. Therefore, we designed this study to investigate (1) the capacity of several of the most frequently used exercise tests to detect post-PR changes among patients with COPD and (2) the correlation between the changes in exercise performance as measured with the tests.

## Methods

### Patients

After obtaining approval from our institution's ethics committee, we recruited 50 consecutive male patients, with the following eligibility criteria:

1. Clinical diagnosis of COPD as defined by the Global Initiative for Obstructive Lung Disease guidelines<sup>10</sup>
2. Presence of dyspnea on exertion that interfered with activities of daily living
3. Stable condition while the patient was receiving treatment and under the care of a medical specialist
4. Ability to ambulate with minimal assistance
5. Absence of contraindications to exercise testing or training
6. Ability to attend the out-patient PR program 3 times a week

We excluded patients with hypoxemia (defined as  $P_{aO_2} < 60$  mm Hg at rest) or who were known to require oxygen supplementation during exercise.

### Pulmonary Rehabilitation Program

The comprehensive PR program consisted of 18 two-hour sessions over 6 weeks in an out-patient (hospital-based) setting. The program included 3 main components:

1. Education. PR staff taught groups of 3–6 patients in informal, group-discussion sessions. Topics included: anatomy and physiology of the lung, pathophysiology of lung disease, medications, nutrition, oxygen therapy, stress management, energy-saving techniques, self-care tips, and

breathing techniques. Patients who were underweight (body mass index  $< 18$  kg/m<sup>2</sup>) or overweight (body mass index  $> 27$  kg/m<sup>2</sup>) were referred for dietary advice and intervention by a dietitian.

2. Physical and respiratory care instruction. Patients received individual instruction in respiratory care and chest physiotherapy techniques, such as postural drainage, pursed-lip and diaphragmatic breathing, flexibility exercises, oxygen therapy, and proper use of respiratory therapy equipment.

3. Supervised exercise training. All patients trained at a target exercise intensity of 70% of the peak work rate, as determined during baseline progressive cycle ergometry. Dyspnea ratings (using the modified Borg dyspnea scale<sup>11</sup>) or absolute power output were used as targets to guide the intensity of exercise during training sessions. The primary exercise-training modalities were walking and cycling. Training emphasized steady-state lower-limb aerobic exercises, consisting of continuous walking or cycling at the targeted work-rate for a period of 20–30 min. For patients who could not tolerate training at that intensity we conducted interval training, consisting of 2–3 min of high-intensity (60–80% of maximum work-rate) training, alternating with equal periods of rest. Patients were also trained in upper-extremity exercise, using an isokinetic upper-body ergometer or weight lifting. Flexibility and stretching exercises (warm-up and cool-down) were taught and performed during each exercise training session.

### Assessment

Patients underwent evaluation of exercise performance before (baseline) and immediately after the 6-week PR program ended. Spirometry at baseline was performed in accordance with recommended standards.<sup>12</sup> All lung function tests were performed with the subject seated and on the same day as (but before) the exercise test. Forced vital capacity and forced expiratory volume in the first second (FEV<sub>1</sub>) were measured with a clinical spirometer (Vmax 229, SensorMedics, Yorba Linda, California). Total lung capacity and its subdivisions were measured by the nitrogen washout method, with the Vmax 229, adhering to standard criteria.<sup>13</sup> Predicted values for FEV<sub>1</sub> and forced vital capacity were determined using the prediction equations from Chia et al.<sup>14</sup> Maximum static inspiratory mouth pressure and maximum static expiratory mouth pressure were measured using pressure gauges (Ashcroft, Farmingdale, New York).

Symptom-limited cardiopulmonary exercise testing was performed using an electronically braked cycle ergometer (Ergometrics 800S, SensorMedics, Yorba Linda, California). After an initial 3 min of unloaded pedaling, the work load was increased automatically by 5 watts every minute until the patient could no longer continue the required

cadence of 40 cycles per minute because of dyspnea or exhaustion. Each subject wore a nose clip and breathed through a mouthpiece connected to a pneumotachograph. Mixed expired oxygen, mixed expired carbon dioxide, and expired volume were measured at rest and for each breath, throughout exercise, using a metabolic cart (Vmax 229, SensorMedics, Yorba Linda, California). The gas analyzer was calibrated for both accuracy and linearity prior to each test. Oxygen uptake ( $\dot{V}_{O_2}$  in mL/min, at standard temperature and pressure, dry), carbon dioxide production ( $\dot{V}_{CO_2}$ , in mL/min), gas exchange ratio, minute ventilation ( $\dot{V}_E$ , in L/min, at body temperature, ambient pressure, and saturated with water vapor), respiratory rate, tidal volume, and the ventilatory equivalent for carbon dioxide ( $\dot{V}_E/\dot{V}_{CO_2}$ ) was determined and averaged every 30 seconds. The peak oxygen uptake ( $\dot{V}_{O_{2max}}$ ),  $\dot{V}_E$ , and heart rate values recorded were the highest values obtained from any 30-s measurement period. Maximum work rate ( $W_{max}$ ) was defined as the highest work level that was reached. Oxygen saturation (measured via pulse oximetry) and heart rate (measured via electrocardiography) were recorded continuously throughout exercise and during recovery. At the end of exercise we recorded the reason(s) for termination, and the Borg dyspnea score.<sup>10</sup>

Exercise endurance was measured after 1 hour of rest following the progressive cycle ergometry. The endurance test was done at a work level based on 80% of the  $W_{max}$  reached during progressive cycle ergometry. After 3 min of unloaded pedaling on the same ergometer that was used for the incremental test, the power output increased to the predetermined work rate level. The patients then continued cycling at the constant submaximal work load until the test was stopped according to the same criteria used during the progressive cycle ergometry, and the endurance time was recorded. The work load of the endurance exercise test after PR is the same as that of the baseline endurance test.

The 6-min walk test was performed on a separate day within a week of the above-described cycling tests. Each patient received standardized instructions that explained the purpose of the test, symptoms that might arise, and reasons to terminate the test.<sup>15</sup> Once familiar with the instructions, and following 2 practice sessions, 2 tests were completed, in a hospital corridor 50 meters in length, with a 30-min rest between the tests. The distance covered during the longest walk was recorded as the 6-min walk distance (6MWD).

### Statistical Analysis

The relationship between 2 sets of data were analyzed using the Pearson correlation test. Comparisons between groups were done with the Student's *t* test for normally distributed continuous variables, and the Mann-Whitney *U* test was used for non-normally distributed continuous vari-

Table 1. Demographic and Pulmonary Function Data\*

	Mean $\pm$ SD	Range
Age (y)	68.3 $\pm$ 7.2	49–87
Body mass index	22.4 $\pm$ 4.1	13.8–32.1
FEV <sub>1</sub> (L)	1.10 $\pm$ 0.41	0.46–1.96
FEV <sub>1</sub> (% of predicted)	47.2 $\pm$ 18.1	19.0–79.0
FVC (L)	2.18 $\pm$ 0.49	1.18–3.13
FEV <sub>1</sub> /FVC (%)	48.9 $\pm$ 10.7	32.0–63.0
TLC (L)	5.48 $\pm$ 0.96	3.97–7.06
RV (L)	3.03 $\pm$ 1.03	1.48–5.37
P <sub>I</sub> max (cm H <sub>2</sub> O)	63 $\pm$ 28	25–132
P <sub>E</sub> max (cm H <sub>2</sub> O)	92 $\pm$ 35	50–203

\*n = 37 (all male)

FEV<sub>1</sub> = forced expiratory volume in the first second

FVC = forced vital capacity

TLC = total lung capacity

RV = residual volume

P<sub>I</sub>max = maximum inspiratory pressure

P<sub>E</sub>max = maximum expiratory pressure

ables. Results are reported as mean  $\pm$  SD. Differences were considered statistically significant when  $p < 0.05$ .

### Results

We studied a total of 37 male patients with COPD who completed the 6-week PR program and who had complete data sets. There was a wide range of percent-of-predicted FEV<sub>1</sub> values (19%–79%). Among these patients, 15 (41%), 16 (43%), and 6 (16%) patients were in the moderate, severe, and very severe stages of COPD, respectively, according to the categorization system proposed by the Global Initiative for Obstructive Lung Disease.<sup>10</sup> Table 1 shows the patients' demographic and physiologic characteristics.

Table 2 shows the pre-PR and post-PR exercise performance values. There were statistically significant improvements in all the indices of exercise performance: 6MWD ( $p < 0.001$ ),  $\dot{V}_{O_{2max}}$  ( $p = 0.004$ ),  $W_{max}$  ( $p = 0.001$ ), and endurance time ( $p < 0.001$ ). Of those indices, the endurance time improved the most significantly, from  $438 \pm 373$  s to  $760 \pm 485$  s (ie, increased  $322 \pm 479$  s). Figure 1 shows the differences in exercise responses to PR. The numbers and percentages of patients who improved were: 27 (73%) in 6MWD, 23 (62%) in endurance time, 22 (59%) in  $\dot{V}_{O_{2max}}$ , and 21 (57%) in  $W_{max}$ . Clinically important improvement in 6MWD ( $\geq 54$  m) was seen with 12 patients (32%). Three patients had negative responses in 6MWD. Figure 2 shows the percent changes in the measures of exercise performance after PR in the 3 exercise tests. The endurance time showed the most striking improvement (144%). The 6MWD,  $\dot{V}_{O_{2max}}$ , and  $W_{max}$  also improved significantly, by 16%, 53%, and 30%, respectively.

## EXERCISE TESTS FOR ASSESSING OUTCOMES OF PULMONARY REHABILITATION

Table 2. Outcome Measurement Tools\*

Index of Exercise Performance	Before PR	After PR	p
$\dot{V}_{O_2\max}$ (mL/min)	860 ± 312	1,032 ± 454	0.004
$W_{\max}$ (watts)	50 ± 24	56 ± 27	0.001
Endurance time (s)	438 ± 373	760 ± 485	< 0.001
6MWD (m)	398 ± 127	434 ± 122	< 0.001

\*Values are means ± SD  
PR = pulmonary rehabilitation  
 $\dot{V}_{O_2\max}$  = maximum oxygen uptake during progressive cycle ergometry  
 $W_{\max}$  = maximum work-rate during progressive cycle ergometry  
6MWD = 6-minute walk distance

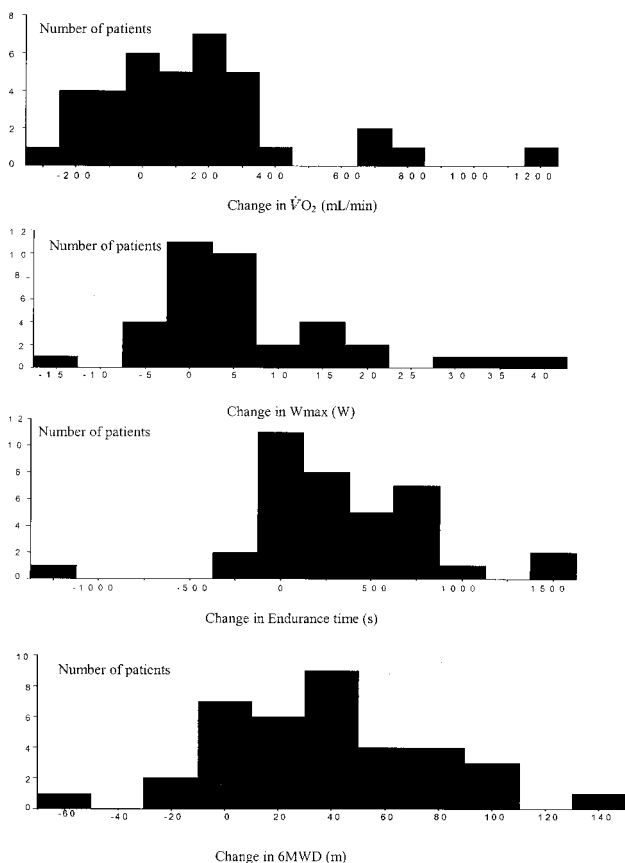


Fig. 1. Effect of pulmonary rehabilitation on exercise performance, as measured by various exercise tests.  $\dot{V}_{O_2}$  = oxygen uptake.  $W_{\max}$  = maximum work-rate during progressive cycle ergometry. W = watts. 6MWD = 6-minute walk distance.

Before PR, all the indices of exercise performance were significantly correlated with one another (Table 3). Table 4 shows the relationships between the post-PR changes in indices of exercise performance. The changes in  $\dot{V}_{O_2\max}$  and  $W_{\max}$  were significantly correlated ( $r = 0.367$ ,  $p = 0.027$ ), as were the changes in endurance time and  $W_{\max}$  ( $r = 0.406$ ,  $p = 0.013$ ). There was no significant correlation between the changes in endurance time and  $\dot{V}_{O_2\max}$ .

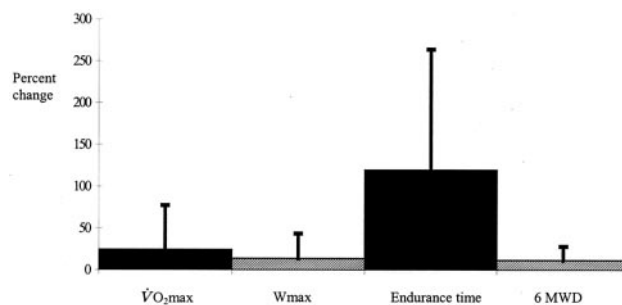


Fig. 2. Mean ± SD changes in various measures of exercise performance after pulmonary rehabilitation, expressed as percent change from baseline.  $\dot{V}_{O_2\max}$  = maximum oxygen uptake.  $W_{\max}$  = maximum work-rate during progressive cycle ergometry. 6MWD = 6-minute walk distance.

Table 3. Correlation Between Exercise Indices at Baseline\*

	6MWD	$\dot{V}_{O_2\max}$	$W_{\max}$	Endurance Time
6MWD	1	0.554†	0.704‡	0.513†
$\dot{V}_{O_2\max}$	0.554†	1	0.694‡	0.652‡
$W_{\max}$	0.704‡	0.694‡	1	0.728‡
Endurance time	0.513†	0.652‡	0.728‡	1

\*Values are Pearson correlation coefficients  
6MWD = 6-minute walk distance  
 $\dot{V}_{O_2\max}$  = maximum oxygen uptake during progressive cycle ergometry  
 $W_{\max}$  = maximum work-rate during progressive cycle ergometry  
† $p = 0.001$   
‡ $p < 0.0001$

Table 4. Correlation Between the Changes in Exercise Indices\*

	6MWD	$\dot{V}_{O_2\max}$	$W_{\max}$	Endurance Time
6MWD	1	0.02	0.188	0.186
$\dot{V}_{O_2\max}$	0.02	1	0.367†	0.199
$W_{\max}$	0.188	0.367†	1	0.406‡
Endurance time	0.186	0.199	0.406‡	1

\*Values are Pearson correlation coefficients  
6MWD = 6-minute walk distance  
 $\dot{V}_{O_2\max}$  = maximum oxygen uptake during progressive cycle ergometry  
 $W_{\max}$  = maximum work-rate during progressive cycle ergometry  
† $p = 0.027$   
‡ $p = 0.013$

The changes in 6MWD were not significantly correlated with changes in any other exercise index.

### Discussion

Comparing the frequently used PR exercise tests, we found that (1) the most responsive index (as measured by the percentage change from baseline) is the endurance

time, and (2) the correlation between the post-PR changes in these exercise indices is poor. In particular, changes in the 6MWD are not significantly correlated to changes in other indices of exercise performance.

The endurance time showed the largest post-PR increase among the 3 exercise tests. Endurance tests measure the ability to sustain a submaximal exercise level, which could characteristically improve when there was no significant increase in maximum exercise capacity. Consistent with what has been previously observed,<sup>7</sup> the  $\dot{V}_{O_{2max}}$  and  $W_{max}$  were insensitive measures of post-PR improvement, compared to the endurance time. It is likely that patients with COPD are more affected by reduced ventilatory capacity during progressive cycle ergometry than during the endurance test.<sup>8</sup> Therefore, it might be insufficient to measure the maximum exercise capacity in the incremental test in patients with COPD. Furthermore, considering that the activities of daily living of patients with COPD are submaximal, measuring the submaximal exercise capacity might be more meaningful than measuring maximal exercise capacity. In the 6-min walk test, patients are known to sustain their steady state just below the maximum exercise capacity that they can reach within 6 min.<sup>15</sup> Thus the 6-min walk test would assess a mixture of endurance and maximal exercise.

The relationship between the post-PR responses in these exercise performance indices requires further elucidation. Oga et al found that the relationships between endurance time and 6MWD,  $\dot{V}_{O_{2max}}$  and  $W_{max}$  were significant ( $r = 0.54-0.55$ ) in a group of patients with COPD.<sup>5</sup> The relationship of the changes in these exercise performance indices after an intervention such as PR are expected to be weaker (as we found in the present study), because PR may impact these indices differently. Nonetheless, there was still significant (but weak) correlation between the post-PR responses in  $\dot{V}_{O_{2max}}$  and  $W_{max}$ , which indicates that the improvement in ability to perform external work was generally accompanied by improvement in aerobic capacity in our patients.

The correlation between the post-PR responses in  $W_{max}$  and endurance time was the strongest among the exercise performance indices, which was expected, since the endurance test was performed at a fixed percentage of the  $W_{max}$  with each patient. The lack of significant correlation between responses in 6MWD and the other exercise indices suggest that this may be due to different exercise testing modes. Recent studies found that among patients with COPD, the ventilatory and metabolic responses during walking are different from those during cycling, perhaps because of the recruitment of a wider range of muscle groups and hence a higher ventilatory demand.<sup>16-18</sup> Nonetheless, previous studies<sup>5,8</sup> with patients with COPD found significant correlation between the 6MWD and  $\dot{V}_{O_{2max}}$ ,  $W_{max}$ , and endurance time measured by cycle ergometry,

which agrees with the correlation we found in the present study between these indices at baseline. Hence, it is likely that the post-PR responses in 6MWD and endurance time are differentially correlated, because the type of exercise training during PR influenced those responses. Like most PR programs (and following evidence-based guidelines<sup>2</sup>) our training program emphasized lower-extremity exercise, but in the present study the exercise consisted more of cycling than walking, which may account for the larger responses measured in the cycling tests than in the walking tests. Tradition has resulted in most pulmonary departments using cycle ergometry for exercise testing. It provides a more stable platform for complex physiologic and metabolic measurements. On the contrary, besides being a less relevant form of exercise for many patients, the different responses observed in the present study in the walking and cycling tests suggest that cycling tests may not adequately assess post-PR changes in walking capacity. Further studies are required to determine if post-PR walking and cycling outcomes are training-type specific.

The results of the present study support the practice of using endurance tests more often for measuring PR outcomes. Although the percentage change from baseline was by far the greatest in endurance time, it is noteworthy that with regard to the number of patients that showed positive post-PR outcomes, there was not much difference when comparing the endurance time with 6MWD. The levels of clinically important changes have been defined for the 6MWD.<sup>19,20</sup> There is also a need to determine what changes in endurance time are clinically important. That may be more challenging because of the wide and varied distribution of changes in post-PR endurance time, as shown in Figure 2. In addition, our results for the endurance test should be interpreted with caution, because it is not as reproducible as progressive cycle ergometry or walking distance.<sup>6</sup> Another clinical corollary is that the results of the 3 commonly used post-PR exercise tests are not interchangeable, because they may evaluate different aspects of post-PR response. The best method for measuring exercise capacity of patients with COPD remains controversial; until one test becomes the accepted standard, it is advisable to continue with various exercise tests, as do some PR programs.

The present study has several limitations. First, the order of the 3 exercise tests was not randomized. Progressive cycle ergometry was performed before the endurance test, to find the appropriate exercise intensity for endurance testing. That may have led to a bias in the performance of the tests. Second, although we have previously found<sup>21</sup> significant outcomes following the PR program described in this study, we acknowledge that there are many variations in PR programs among different PR centers and our findings may not be applicable to other PR programs, especially relating to the exercise training component.

### Conclusions

Among the frequently used post-PR exercise tests, the most responsive index, as measured by the percentage change from baseline, is the endurance time. The correlation between the post-PR changes in these exercise indices is poor.

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