Maximum Intensity Exercise Training in Patients with Chronic Obstructive Pulmonary Disease*

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We studied high intensity, symptom-limited, endurance exercise training in 52 patients with COPD participating in a pulmonary rehabilitation program. The patients had moderate to severe airway obstruction and reduced exercise tolerance with ventilatory limitation. The target workload for endurance exercise testing was 95 percent of the baseline maximum treadmill work load. At training weeks 1, 4 and 8, they were training at 85, 84, and 86 percent respectively, of baseline maximum. After rehabilitation, there was an increase in maximal treadmill work load, $\dot{V}o_2$max, and endurance exercise time, and a decrease in perceived symptoms. Patients who did not reach anaerobic threshold (group 2) were able to train at a higher percentage of maximum exercise tolerance than patients who reached anaerobic threshold (group 1). The increase in exercise performance of both groups, however, was similar. We conclude that patients with moderate to severe COPD can perform exercise training successfully at intensity targets which represent higher percentages of maximum than typically recommended in normal individuals or other patients. *(Chest 1991; 100:618-23)*

ANOVA = analysis of variance; AT = anaerobic threshold; COPD = chronic obstructive pulmonary disease; Dsb = single-breath CO diffusing capacity; FEF25-75% = mean forced expiratory flow during the middle half of FVC; FEV_1 = forced expiratory volume in 1 s; FRC = functional residual capacity; FVC = forced vital capacity; HR = heart rate; MEP = maximum expiratory pressure; METs = metabolic equivalents ($\dot{V}o_2$ estimated from treadmill speed/grade); MIP = maximum inspiratory pressure; MVV = maximum voluntary ventilation; $PaCO_2$ = arterial carbon dioxide pressure; PaO_2 = arterial oxygen pressure; pH = negative logarithm of hydrogen ion activity; R = respiratory exchange ratio; Raw = airway resistance; RV = residual volume; SaO_2 = arterial oxygen saturation; TLC = total lung capacity; $\dot{V}co_2$ = carbon dioxide production per minute; $\dot{V}$E = minute expired ventilation; $\dot{V}o_2$ = oxygen consumption per minute

Pulmonary rehabilitation programs for patients with COPD are well established as a means of enhancing standard medical therapy in order to alleviate symptoms and improve function.[1-7] The primary goal of such programs is to restore the patient to the highest possible level of independent function. Exercise has been included as an important component in pulmonary rehabilitation. However, in contrast to well-developed guidelines for exercise training in normal subjects or cardiac patients, there are few established guidelines for the appropriate exercise prescription for patients with lung disease.[3,4,8-10] In planning exercise programs for pulmonary patients, principles of exercise training derived from normal individuals are commonly misapplied to these patients whose exercise tolerance is limited by factors other than heart and skeletal muscle function.[8,11]

One area of particular controversy in prescribing exercise for patients with COPD has been the selection of appropriate intensity targets.[12] Some authors have advocated use of HR targets at submaximal percentages of maximum similar to the principles used for normal individuals or patients with cardiac disease.[12-14] Others have proposed that symptom-limited targets are more appropriate for such patients.[4,8,15,16]

We have found that many patients with severe lung disease, particularly those who are ventilatory-limited, can be trained at a high percentage of maximum exercise tolerance that may approach or even exceed the highest level reached on initial maximum exercise testing.[17] The principle of high-intensity exercise training is based on the observation that such patients can sustain ventilation at a high percentage of their MVV.[18]

The purposes of this study were (1) to examine our experience with high-intensity, symptom-limited endurance exercise training in the rehabilitation of patients with COPD, and (2) to develop guidelines for such training.

Methods

Subjects

The study population consisted of 57 patients with COPD who were assigned to pulmonary rehabilitation as part of a randomized clinical trial comparing education alone vs comprehensive pulmonary rehabilitation including individualized exercise training. All patients met the following entry criteria: (1) clinical diagnosis of COPD confirmed by history, physical examination, spirometry and chest roentgenogram; (2) stable condition while receiving an acceptable medical regimen prior to entry; (3) no other significant lung disease; and (4) no unstable cardiac disease or other medical problem which would limit participation in the rehabilitation program.

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Baseline Testing

Pulmonary Function Tests: Each patient underwent pulmonary function tests including spirometry, lung volumes and Raw by body plethysmography, Dsb, MVV and MIP and MEP. Spirometry, lung volumes, and Raw tests were repeated after two puffs of inhaled metaproterenol. Testing and quality control procedures followed standard and recommended methods.[19,20] Normal values used were those of Morris and co-workers[21] for spirometric data, Goldman and Becklake[22] for lung volumes, Miller and co-workers[23] for Dsb and Black and Hyatt[24] for maximal respiratory pressures.

Exercise Tests: Exercise testing was performed in two steps to evaluate (1) maximum exercise tolerance and (2) endurance at high-percentage training targets.

Each patient performed an incremental, symptom-limited exercise test to the maximal tolerable level on a treadmill. A radial arterial catheter was inserted percutaneously for arterial blood sampling. Arterial oxygen saturation was monitored continuously by ear oximetry (Ohmeda; Boulder, CO). The SaO_2 measurements were recorded simultaneously with each arterial blood sample. Electrocardiogram was monitored prior to and during the test. Blood pressure was taken manually at periodic intervals.

Patients were tested on a treadmill connected to a mixing chamber through a low-resistance breathing valve (Hans Rudoph; Kansas City, MO) for expired gas measurements. After a stable rest period, each patient walked at 1.0 miles per hour for 3 min; the work load was then increased each minute until the patient reached a symptom-limited maximum or the test was terminated due to ear oximetry SaO_2 less than 85 percent, ST-T wave depression or serious arrhythmia noted on the ECG, or an excessively elevated blood pressure (*eg*, systolic pressure greater the 250 mm Hg). At the end of the test, patients rated symptoms of breathlessness and fatigue using a scale modified from Borg.[25] Anaerobic threshold was determined noninvasively by examining the pattern of changes in the ventilatory equivalents of O_2 ($\dot{V}E/\dot{V}O_2$) and CO_2 ($\dot{V}E/\dot{V}CO_2$) as well as the R with increasing work loads. Patients with significant hypoxemia were retested and trained on supplemental oxygen in an amount adequate to raise both the resting and exercise PaO_2 greater than 55 mm Hg.

Based on the results of the incremental, maximum treadmill exercise test, each patient was given a target intensity for endurance exercise training based on the following principles:

1. Maximum work load reached for patients without respiratory evidence of significant lactic acidosis at maximum exercise (*ie*, below AT).
2. Work load associated with AT, if reached, during the exercise test.

On a separate day after the incremental exercise test, each patient performed an endurance exercise test on a treadmill at the work level indicated by the target training intensity. In this test, patients walked on the treadmill for 2 min at 1.0 miles per hour, 2 min at a work level just below the target and then for a maximum of 20 min at the target work load. If they were able to sustain the target work load for 20 min, the work level was increased further to the next higher work load up to an additional 10 min (*ie*, maximum of 34 min of continuous treadmill walking). Patients with low targets (*eg*, 0.6 to 1.0 miles per hour) were started at those levels. Patients were asked to continue walking as long as could be tolerated and to rate symptoms of perceived breathlessness and fatigue at the end of the test.

Exercise Training

Patients were instructed to perform daily walking exercise training at target levels based on the results of the initial exercise tests. Training was supervised on a treadmill during scheduled rehabilitation program sessions twice weekly for the first four weeks, then once weekly for four more weeks. Training was started at a level that the patients could sustain for several minutes, often just below the target selected for the endurance test. At home, they trained daily at a walking pace approximating their sustained treadmill speed. The few patients training with a treadmill grade were instructed to increase their walking speed or duration, or both, slightly. Training levels (miles per hour or grade or both) were subsequently increased, as tolerated, only during supervised rehabilitation program sessions. All patients kept daily exercise diaries to monitor training progress.

Follow-up Testing

After completing the eight-week rehabilitation program, patients performed pulmonary function tests (while receiving regular medications without post-bronchodilator testing) and both the maximum and endurance exercise tests in identical fashion to the baseline protocol but without arterial blood sampling.

Statistical Analyses

Descriptive statistics were calculated for measurements of lung function and exercise performance before and after rehabilitation and compared by paired *t* tests. The patients also were subdivided into two groups based on whether they did (group 1) or did not (group 2) show evidence of reaching a respiratory AT on baseline maximum exercise testing. Descriptive statistics were calculated for each group for selected variables at baseline and compared by unpaired *t* tests. Finally, multiple stepwise regression was utilized to assess whether selected baseline characteristics could be used to predict the percentage work level achieved during training at the end of eight weeks.

Results

Baseline data from 52 of the 57 patients were analyzed. Five patients were excluded because they did not reach a maximum symptom limit during the initial incremental exercise test due to low oxygen saturation (one), elevated systolic/diastolic blood pressure and low SaO_2 (one), cardiac arrhythmia (one), dry mouth (one) and gagging on the mouthpiece (one).

Attendance at scheduled rehabilitation program sessions was good. Patients attended a mean of 10.7 out of 12 clinic visits (88.9 percent). After rehabilitation, data were available on 46 patients for statistical analyses. Two patients moved before completing the eight-week program; four patients completed the program but were not retested due to illness (two), sudden cardiac death (one) and failure to complete tests (one).

Results from the pulmonary function and exercise tests at baseline and after the two-month rehabilitation program are shown in Table 1. Overall, patients had moderate to severe expiratory flow obstruction, hyperinflated lung volumes, mild resting hypoxemia and normocapnea. After completing the rehabilitation program there were no significant changes in lung function measurements. The baseline exercise test showed reduced maximum exercise tolerance with ventilatory limitation (*ie*, high $\dot{V}E$/MVV ratio). In order to provide a single quantitative measure for treadmill workload for data analysis, treadmill speed and grade were converted to estimated $\dot{V}O_2$ using a standard formula for calculation of METs.[26] Six patients required sup-

Table 1—*Pulmonary Function and Exercise Tests Results**

	Baseline (n=52)	After Rehabilitation (n=46)
Age, yr	61.6±8.3	
Pulmonary function		
FVC, L	3.09±0.85	3.03±0.82
FEV_1, L	1.38±0.67	1.34±0.58
FEV_1/FVC, %	43.6±13.0	43.7±11.9
FEF25-75%, L/s	0.58±0.59	0.51±0.32
MVV, L	45.5±24.7	50.7±22.5
TLC, L	7.49±1.66	7.68±1.84
FRC, L	5.33±1.61	5.53±1.80
RV/TLC, %	54.5±11.0	55.7±10.7
Resting arterial blood gas values (room air)		
PaO_2, mm Hg	75.2±11.4	
$PaCO_2$, mm Hg	38.0±5.0	
pH	7.44±0.04	
Maximum exercise test		
Maximum treadmill work load, METs	4.7±2.9	6.2±3.5†
$\dot{V}O_2$max, L/min	1.25±0.52	1.37±0.59‡
$\dot{V}O_2$max, ml/kg/min	17.0±6.4	18.6±6.9‡
$\dot{V}E$max, L/min	45.5±20.0	49.4±20.5§
$\dot{V}E$max/MVV	1.07±0.30	1.02±0.27
HRmax, breaths per minute	135±18	138±18
Perceived symptoms		
Breathlessness	5.4±1.6	4.6±2.1§
Fatigue	4.3±2.3	3.5±2.0§
$\dot{V}O_2$ at AT, L/min (n=18 who reached AT)	1.36±0.31	1.48±0.39
Endurance exercise test		
Endurance time, min	12.1±8.4	22.0±10.9‖
Perceived symptoms		
Breathlessness	5.0±2.1	3.7±2.0§
Fatigue	4.3±2.2	2.9±1.7§
Target treadmill work load, METs	4.2±2.4	
Target/baseline maximum work load in METs, %	95±18	

*Data presented as mean±SD.
†Compared with baseline $p<0.0001$.
‡Compared with baseline $p<0.01$.
§Compared with baseline $p<0.05$.
‖Compared with baseline $p<0.001$.

plemental oxygen at rest or exercise, or both. After rehabilitation, exercise tolerance improved with a significant increase in maximal treadmill work load (estimated $\dot{V}O_2$ in METs), $\dot{V}O_2$max, and $\dot{V}E$max and a decrease in perceived breathlessness and fatigue. There was no significant change in maximum HR or in $\dot{V}O_2$ at AT (for the 18 subjects who showed evidence of reaching AT at baseline).

For the endurance exercise test, it can be seen in Table 1 that the average target intensity work level represented a high percentage of the maximum work load achieved on baseline exercise testing (95 percent). At this level, patients were able to walk for 12.1 min on the endurance test. After the rehabilitation program, there was a significant increase in endurance exercise time with less perceived breathlessness and fatigue.

Table 2—*Limitations to Maximum Exercise*

Limitation	Baseline (n=52)	After Rehabilitation (n=46)
Dyspnea	26	22
Muscle (fatigue/cramps)	10	5
Dyspnea and muscle	5	5
Dyspnea and other*	5	3
Muscle and other*	1	2
Low SaO_2	1	1
Others*	4	8
*Other Limitations		
Dizziness	5	5
Mouthpiece problems	3	2
Arrythmia	1	1
Balance	1	0
Low SaO_2	0	1
Back/joint pain	0	4

The limitations to maximum exercise tests are presented in Table 2. At baseline, dyspnea was the most common limiting symptom reported in 36 out of 52 patients (69 percent), followed by muscle symptoms in 16 out of 52 patients (31 percent). After rehabilitation, dyspnea also was the most common limiting symptom reported (65 percent), followed by muscle symptoms (26 percent).

In order to assess progress during training, the work load and duration during supervised treadmill exercise sessions were obtained from each patient's training diary at weeks 1, 4 and 8 of the rehabilitation program. In addition, the training $\dot{V}O_2$, $\dot{V}E$ and HR at week 8 were estimated from measurements obtained at the corresponding work load during the post-rehabilitation incremental exercise test performed near that time. The percentages of baseline maximum work load (in METs) for the target level of the endurance exercise test, as well as for training weeks 1, 4 and 8, are

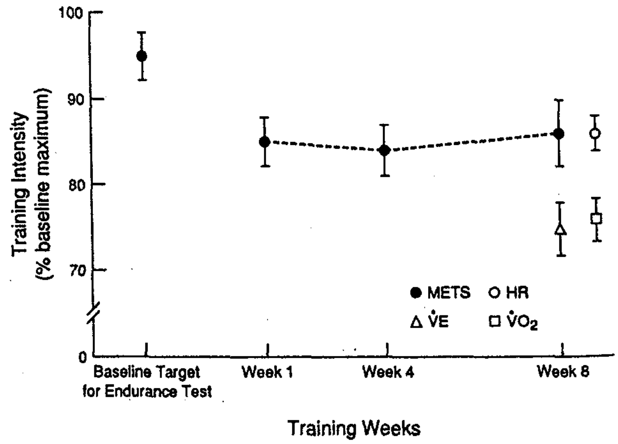

FIGURE 1. Percentage of baseline maximum work load in METs for target level of the endurance exercise test and training weeks 1, 4 and 8. Also indicated are percentage of baseline maximum achieved at training week 8 for $\dot{V}O_2$, $\dot{V}E$ and HR.

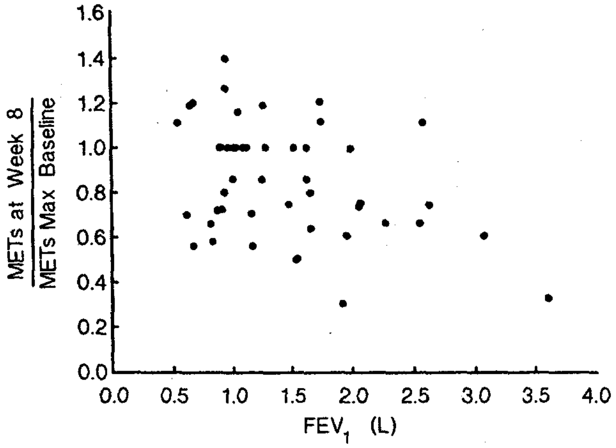

FIGURE 2. Relationship of FEV_1 and ratio of treadmill work load at week 8 of training to baseline maximum work load.

presented in Figure 1. In addition, the percentage of baseline maximum achieved at week 8 of training for $\dot{V}O_2$, $\dot{V}E$ and HR also are indicated. These results demonstrate that, on average, patients were exercising at high percentages that exceeded baseline maximum levels in many cases.

Significant improvement in perceived symptoms during training occurred progressively through the eight-week rehabilitation program. Ratings of perceived breathlessness decreased from 3.6 ± 1.6 at week 1 to 3.1 ± 1.7 at week 4 and to 2.6 ± 1.6 at week 8 ($p<0.0001$ by repeated measures ANOVA). Similarly, ratings of perceived fatigue decreased from 3.3 ± 1.5 to 2.8 ± 1.3 to 2.5 ± 1.4 at weeks 1, 4 and 8, respectively ($p<0.001$).

To better understand the determinants of the training intensity reached during rehabilitation, selected baseline characteristics were compared with the percentage of baseline maximum work load achieved during training. Based on the initial strategy for selecting training targets, we expected that patients with more severe lung disease who were ventilatory-limited would achieve high percentages of maximum during training. In contrast, patients with less severe disease (who may reach higher absolute exercise levels and exceed AT) would not be expected to reach as high a percentage of baseline maximum during training. The relationship of FEV_1 to percentage of work load achieved during training (METs at week 8/METs max at baseline) is presented in Figure 2. These results indicate that patients with more severe disease did, in general, reach a higher percentage of their initial maximum work load during training, but that the relationship was quite variable ($r = -0.38$, SEE = 0.24).

Since maximum targets were selected primarily for patients who did not reach AT during initial exercise testing, we then grouped patients according to whether an AT could be determined from expired gas measurements. As indicated in Table 3, patients who did not reach AT (group 2) had more severe disease, as evidenced by significantly lower FEV_1, MVV, PaO_2 and $\dot{V}O_2$max. They also reached higher percentage targets than the more functional patients (group 1) who did reach AT (100 vs 85 percent, respectively). Also, there were no significant differences between perceived symptom ratings between the two groups during either maximum or endurance exercise testing. The results in Table 3 also indicate that both groups demonstrated similar improvement in exercise performance and reduction in perceived symptoms after the rehabilitation program.

Finally, stepwise multiple regression analysis was performed in an attempt to determine if the percentage work level achieved during training could be

Table 3—*Pulmonary Function and Exercise Test Results of Patients Who Did (Group 1) and Did Not (Group 2) Reach Anaerobic Threshold**

	Group 1 (n = 18)	Group 2 (n = 34)
Baseline		
FEV_1, L	1.96 ± 0.74	1.07 ± 0.37†
MVV, L/min	65.7 ± 28.2	34.7 ± 13.9‡
PaO_2, mm Hg (rest)	81.6 ± 12.1	71.7 ± 9.6§
$PaCO_2$, mm Hg (rest)	36.1 ± 4.0	39.0 ± 5.2‖
$\dot{V}O_2$max, L/min	1.74 ± 0.43	0.99 ± 0.35†
$\dot{V}O_2$max, ml/kg/min	22.6 ± 5.9	14.1 ± 4.5†
$\dot{V}E$max, L/min	64.8 ± 16.5	35.3 ± 12.9†
$\dot{V}E$max/MVV	1.09 ± 0.35	1.05 ± 0.28
Endurance time, min	14.0 ± 9.2	11.3 ± 8.0
Target/baseline maximum treadmill work load (METs), %	85 ± 14	100 ± 18§
Perceived symptoms		
Maximum exercise		
Breathlessness	5.5 ± 1.5	5.4 ± 1.6
Fatigue	5.2 ± 2.3	4.0 ± 2.1
Endurance walk		
Breathlessness	5.6 ± 2.4	4.7 ± 1.8
Fatigue	4.9 ± 2.7	4.0 ± 1.8
After Rehabilitation		
Week 8 training/baseline maximum treadmill work load (METs), %	72 ± 21	94 ± 24§
Change (2 mo to baseline)		
Maximum treadmill work load, METs	1.7 ± 1.3	1.3 ± 1.4
$\dot{V}O_2$max, L/min	0.14 ± 0.31	0.08 ± 0.16
$\dot{V}O_2$max, ml/kg/min	1.4 ± 4.2	1.1 ± 2.3
Endurance time, min	8.8 ± 11.6	9.7 ± 9.9
Perceived symptoms		
Maximum exercise		
Breathlessness	−0.3 ± 2.1	−1.0 ± 2.3
Fatigue	−1.2 ± 2.5	−0.6 ± 2.5
Endurance walk		
Breathlessness	−1.8 ± 1.6	−1.2 ± 1.9
Fatigue	−1.6 ± 2.1	−1.1 ± 2.2

*Data presented as mean ± SD.
†Compared with group 1 $p<0.0001$.
‡Compared with group 1 $p<0.001$.
§Compared with group 1 $p<0.01$.
‖Compared with group 1 $p<0.05$.

predicted from 12 baseline variables selected as representative characteristics of lung function, exercise tolerance and compliance with the rehabilitation program. In this analysis, only $\dot{V}_E$ at maximum exercise was found to be a significant independent variable ($r = 0.54$, $SEE = 0.21$) for prediction of the ratio of METs at week 8 to baseline maximum.

Discussion

The results of this study demonstrate that many patients with moderate to severe obstructive lung disease can undergo exercise training successfully at target intensities which are a considerably higher percentage of maximum than those typically recommended in normal individuals or patients with other diseases. Patients with ventilatory limitation to maximum exercise tolerance who did not develop significant metabolic acidosis during incremental exercise testing were able to train at levels approaching, and even exceeding in many cases, the maximum level reached on initial testing. Patients who exceeded their AT during baseline testing were generally able to train at levels which were at higher percentages of maximum than typical for normal individuals.

It should be emphasized that these results do not indicate that this training method is necessarily the best one for prescribing training intensity for patients with chronic lung disease. The purpose of this report is to highlight the differences in principles of exercise training which may be appropriate for these patients. Clearly, additional studies are needed to compare different training regimens in pulmonary patients. Nevertheless, it is common practice to exercise these patients, who train at low absolute levels consistent with the severity of their underlying lung disease, to their symptom limits. Our experience does indicate that maximum intensity exercise training is both safe and effective in these patients.

Exercise is widely accepted as an important mode of treatment in the rehabilitation of patients with COPD.[1-7] In this study, the target intensity selected for exercise training for the majority of patients who were ventilatory-limited without evidence of metabolic acidosis was the highest work load reached on initial maximum exercise testing. Training intensity was generally begun at levels just below this target and increased as tolerated by symptom limits. Most patients were instructed to exercise to a level of breathing discomfort which they could estimate using a perceived symptom scale. At the end of the eight-week rehabilitation program, these patients were walking at a work level of 86 percent of their baseline maximum for a mean duration of 22 min.

For patients with less severe COPD who showed evidence of metabolic acidosis during initial maximum exercise testing, training intensity was selected to be just above AT. This level, on average, was 85 percent of baseline maximum. In the 18 patients who did reach AT during initial exercise testing, the work load achieved during eight weeks of training averaged 72 percent of baseline maximum.

In terms of the benefits derived from the exercise program, both patients who did and did not reach AT showed similar improvement in maximum work load (METs max), $\dot{V}O_2$max, time in the endurance exercise test and perceived symptom ratings. There were no significant differences in the changes noted in either group. This contrasts with the suggestions of Wasserman and co-workers[27] and Casaburi and co-workers[28] that determination of AT during exercise can be helpful in selecting patients who benefit from exercise training. Our results show that both groups had comparable improvements after two months of exercise training.

As expected, there were significant correlations between baseline measurements reflecting disease severity and the percentage of baseline maximum work load reached during training. Patients with more severe disease, in general, reached higher percentages of their baseline maximum during training (although the absolute training levels were lower). However, the multiple stepwise regression analysis indicated that the baseline characteristics examined did not add significantly to the prediction of training percentage. This would suggest that the best predictor of the level achieved during training was the measured maximum work load during the baseline exercise test.

In training patients to symptom tolerance, ratings of perceived symptoms (*eg*, breathlessness) help to teach patients to exercise to "target" levels of breathing discomfort. In a study of 59 patients with moderate to severe COPD, Carter and co-workers[16] trained patients at levels near their ventilatory limits. At baseline, after training and three months later, they reported mean peak exercise ventilation of 94 to 100 percent of measured MVV. Patients improved maximum exercise levels and ventilation with training. Other authors note that training above the AT will lead to a reduced ventilatory requirement during exercise and, therefore, improved maximum exercise tolerance in these patients.[28]

In summary, the results of this study indicate that patients with moderate to severe COPD can perform exercise training successfully at symptom-limited intensity levels which represent high percentages of their maximum exercise tolerance. Many of the patients in this study, particularly those with more severe lung disease and ventilatory limitation to exercise performance, were able to train at levels that approached or even exceeded the maximum achieved during initial exercise testing.

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