Effect of Respiratory Muscle Endurance Training in Patients With COPD Undergoing Pulmonary Rehabilitation*

M. Jeffery Mador, MD; Omar Deniz, MD; Ajay Aggarwal, MD; Mary Shaffer, NP; Thomas J. Kufel, MD; and Christina M. Spengler, PhD

Background: Respiratory muscle endurance training (hyperpnea training) has been shown to have beneficial effects in patients with COPD.

Study objectives: The purpose of this study was to determine whether hyperpnea training, when added to an endurance exercise training program, would lead to additional benefits compared with endurance training alone in patients with COPD.

Setting and participants: Patients with COPD entering an 8-week outpatient pulmonary rehabilitation program. Fifteen patients (mean ± SE FEV1, 45 ± 6% predicted) were randomized to combined therapy, and 14 patients (mean FEV1, 44 ± 4% predicted) were randomized to endurance training.

Methods: Peak exercise capacity, exercise endurance time during constant workload cycle exercise, 6-min walk distance, quality of life as measured by the chronic respiratory questionnaire, respiratory muscle strength and endurance, and quadriceps fatigability were measured before and after end and endurance or combined training.

Results: After rehabilitation, peak exercise capacity, exercise endurance time, 6-min walk distance, and quality of life all increased in both groups, but there was no significant difference in the extent of improvement between groups. Mean respiratory muscle endurance increased to a significantly greater extent in the combined therapy group (17.5 ± 2.7 vs 8.5 ± 2.5 min, respectively; p = 0.02). Respiratory muscle strength was significantly increased, and quadriceps fatigability was significantly reduced after rehabilitation in the combined therapy group but not in the endurance training group, but the difference between groups did not reach statistical significance.

Conclusion: The endurance of the respiratory muscles can be improved by specific training beyond that achieved by endurance training alone in patients with COPD. However, this improvement did not translate into additional improvement in quality of life or exercise performance.

Key words: COPD; exercise; exercise therapy; muscles; pulmonary disease; rehabilitation; skeletal

Abbreviations: MVV = maximum voluntary ventilation; Pmax = maximal expiratory pressure; Pimax = maximal inspiratory pressure; VE = minute ventilation; Wmax = maximal work capacity

Patients with advanced COPD have impaired exercise tolerance, which limits their activities of daily living. Dyspnea is a limiting symptom in a significant proportion of patients. Just like other muscles, the respiratory muscles can be trained specifically if an adequate training stimulus is applied. It has been hoped that training of the respiratory muscles would lead to improved exercise performance and a reduction in dyspnea in patients with COPD. Most prior studies have trained the respiratory muscles using resistive or threshold breathing. When such breathing tasks have been added to an endurance exercise training program, it has been difficult to demonstrate any additional

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Supported in part by Swiss National Science Foundation grant No. 31–61941.00.

Manuscript received March 15, 2004; revision accepted December 1, 2004.

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improvement in exercise performance from that achieved by endurance training alone. However, many of these protocols had been designed to primarily increase respiratory muscle strength rather than endurance. Voluntary hyperpnea may be a qualitatively better training stimulus than resistive or threshold breathing. A training device has been developed that simplifies our ability to perform hyperpneic training and has been successfully used to train patients with COPD in a home setting.

Normocapnic hyperpneic training has resulted in improved exercise performance and quality of life in patients with COPD in some but not all studies. However, its utility in patients already undergoing endurance exercise training remains to be determined. The purpose of this study was to determine whether the addition of hyperpnea training to an endurance exercise training program would provide any additional benefits from those achieved by endurance training alone in patients with COPD.

**Materials and Methods**

**Subjects**

Thirty-eight consecutive patients with COPD who entered our pulmonary rehabilitation program agreed to participate in the study. Patients were grouped into classes of three to five patients. Each class was randomly assigned to endurance training alone or endurance training plus hyperpneic (combined) training. Nineteen patients were randomized to both the endurance training group and the combined training group. Five patients in the endurance therapy group and three patients in the combined therapy group failed to complete the rehabilitation program; one patient in the combined therapy group refused postrehabilitation measurements. Thus, there were 14 patients in the endurance training group and 15 patients in the combined training group who completed the protocol. The study was approved by the appropriate institutional review boards, and written informed consent was obtained from all of the subjects.

The diagnosis of COPD was made by a clinical course that was consistent with chronic bronchitis and/or emphysema, a long history of cigarette smoking (mean \[\pm SE\] duration, 76.8 ± 9.8 pack-years), and pulmonary function test findings revealing irreversible airflow obstruction. Twenty-seven of the patients who completed the study were receiving inhaled \(-\)-agonist agents, 26 patients were receiving inhaled anticholinergic agents, 21 patients were receiving inhaled steroids, and 5 patients were receiving oral theophylline therapy. Two patients, one in each group, were receiving oral prednisone therapy. Four patients (two in each group) were receiving continuous supplemental oxygen, and two patients (one in each group) were prescribed supplemental oxygen with exertion.

One patient in the combined training group had chronic hypercapnia (defined as a PCO\(_2\) > 45 mm Hg during a period of clinical stability). To be eligible for our pulmonary rehabilitation program, patients had to have successfully quit smoking for \(\geq 3\) months prior to assessment.

**Pulmonary Function Testing**

Spirometry was performed according to American Thoracic Society recommendations. Lung volumes were measured by body plethysmography, and single-breath diffusing capacity was also measured. The predicted normal values were those of Crapo and colleagues. Maximal inspiratory pressure (Pimax) and maximal expiratory pressure (Pemax) were measured with a differential pressure transducer (model MP-45, ± 350 cm H\(_2\)O; Validyne Corp; Northridge, CA) while performing maximal inspiratory and expiratory efforts against an occluded airway near residual volume and total lung capacity, respectively. The highest pressure sustained for at least 1 s from among 5 to 10 measurements was recorded.

**Respiratory Muscle Endurance Testing**

Respiratory muscle endurance was tested using the same device that was used during hyperpnea training (see next section). Similar to the training sessions, the subjects were connected to a metabolic cart, and minute ventilation (Ve), end-tidal CO\(_2\) (PetCO\(_2\)), and oxygen saturation were continuously monitored. The subjects were asked to maintain a target Ve of 70% of the 12-s maximum voluntary ventilation (MVV). The MVV was measured three times, and the best result was chosen. When the subject could no longer maintain the target Ve, despite his/her best efforts, the test was stopped, and the endurance time was calculated. The respiratory muscle endurance was measured three times, and the longest endurance time was chosen for analysis. The patients performed two endurance tests on 1 day (separated by a 30-min rest period), and the third test was performed on a separate day. After rehabilitation, the subjects were allowed to stop if they maintained the target Ve for 40 min.

**Exercise Testing and Quality of Life**

An incremental symptom-limited exercise test was performed to determine the maximal work capacity of each subject. After a 3-min acclimatization period and 1 min of pedaling at 0 W, the workload was increased by 10 W every minute until the subject could no longer continue. The last workload for which a subject was able to complete 30 s of cycling was designated the maximal work capacity (Wmax).

Several days after the incremental exercise test, a constant workload exercise (endurance) test was performed on an electronically braked cycle ergometer at 60 to 70% of Wmax to volitional exhaustion. The subjects were allowed 3 min to acclimatize to the breathing circuit, then they exercised for 1 min at 0 W and 2 min at 10 W (ie, the warm-up period) before initiating exercise at 60 to 70% of Wmax. The patients who were receiving oxygen during exercise breathed from a 200-L reservoir bag containing 35% O\(_2\). After pulmonary rehabilitation was complete, three exercise tests were performed on separate days. On the first day, the maximal exercise test was repeated. Isowork comparisons were made at the highest workload reached both before and after rehabilitation. On the second day, the endurance test was repeated, and the test was stopped by the investigator when the prehabilitation endurance time was reached (for quadriceps measurements). On the final day, the endurance test was repeated, but the patient was allowed to continue exercising to the limits of tolerance (to evaluate any potential improvement in exercise endurance). After rehabilitation, the subjects were allowed to stop after 40 min of endurance exercise even if they could continue exercising. Isotrace comparisons were made at the fastest time reached both before and after rehabilitation.

Six-minute walk tests were administered before (the best of three tests) and after completion of the rehabilitation program (the best of three tests) as additional tests of functional capacity. Subjects were given standardized instructions to cover the greatest distance possible in 6 min. Standardized verbal encouragement was given each minute. The nurse supervising the walks was blinded to the subject’s group.
Health-related quality of life was measured with the chronic respiratory questionnaire, which was administered by a trained interviewer. The interviewer was blinded to the subject’s group.

**Quadriceps Fatigability**

The purpose of obtaining measurements of quadriceps fatigability was to help determine the potential mechanisms for any improvement in exercise performance observed with hyperpneic training. Hyperpneic training has been thought by some to act as an ergonomic aid augmenting exercise performance at least in healthy subjects. We hypothesized that hyperpneic training might reduce dyspnea during exercise and might allow subjects to advance more quickly during the endurance exercise sessions, thus augmenting the training response. Alternatively, hyperpneic training might only substantially reduce dyspnea or the response to dyspnea during peak exercise and, thus, might have little effect during training but could still augment performance during the more strenuous testing sessions. We reasoned that if hyperpneic training facilitated exercise training, it would lead to greater reductions in quadriceps fatigability than that achieved by endurance training alone, whereas if hyperpneic training made subjects more tolerant of extreme dyspnea (ie, dyspnea desensitization), it might lead to improvements in exercise performance without any change in the degree of quadriceps fatigability. Quadriceps fatigability was assessed by measuring the quadriceps twitch force during supramaximal magnetic stimulation of the femoral nerve before and after endurance exercise on the cycle. The quadriceps twitch force was measured as previously described. In many of the patients, the magnetic stimulation of the femoral nerve elicited a large shock artifact that obscured the compound motor action potential (M wave). However, with careful positioning of the surface electrodes and ground, M waves were obtained before rehabilitation in 23 patients and after rehabilitation in 24 patients. After a vigorous voluntary contraction, the subsequent action potential (M wave). However, with careful positioning of the surface electrodes and ground, M waves were obtained before rehabilitation in 23 patients and after rehabilitation in 24 patients. After a vigorous voluntary contraction, the subsequent twitch was used for all calculations (StatView; SAS Institute; Cary, NC).

Data are expressed as the mean ± SE. Changes in variables over time and between groups were analyzed by repeated-measures analysis of variance. Baseline values for the two groups were compared by unpaired t test. A p value of < 0.05 was considered to be significant. A statistical software package was used for all calculations (StatView; SAS Institute; Cary, NC).

**Exercise Training**

**Endurance Training.** On the cycle ergometer, patients initially exercised at 50% of the Wmax achieved during the maximal incremental exercise test. When the patients could exercise for 20 min without intolerable dyspnea or leg fatigue (defined as a Borg rating of breathlessness and leg effort of ≤ 5 during exercise), the workload was increased by 10%. Treadmill exercise was started at a speed ranging from 1.1 to 2.0 miles per hour at 0% elevation based on the patient’s functional capacity (ie, on 6-min walk results). When the patients could exercise for 20 min without intolerable dyspnea or leg fatigue, the speed and/or elevation was increased. The patients had a brief warm-up and cool down after each exercise bout. At the beginning of each session, a series of stretching exercises was performed. The patients also performed a series of calisthenics with and without small weights. The patients also received weekly 1-h educational classes consisting of informal small-group discussions on topics thought to be relevant in the rehabilitation of patients with COPD.

**Hyperpnea Training.** Subjects breathed from a rebreathing bag while obtaining fresh air through a side port. Ve and PETCO2 were continuously recorded using a metabolic cart (MedGraphics; St. Paul, MN), and oxygen saturation was measured by pulse oximetry. Rebreathing bags of 1.5 to 2.0 L, depending on the patient’s vital capacity, were used, and the size of the bag was additionally adjusted with a clamp until stable normocapnia as estimated by the PETCO2 was obtained during preliminary trials. If hypocapnia occurred, the size of the bag was increased, and if hypercapnia occurred, the size of the bag was decreased. The subjects wore noseclips during hyperpnea training to ensure that they breathed exclusively through the training device. In the patients who were receiving supplemental oxygen, the hyperpnea training was done without oxygen. In these patients, modest hypocapnia was achieved during hyperpnea training by increasing the size of the fresh air port. This prevented significant hypoxemia during the hyperpneic training and was well-tolerated. A similar strategy was used in the hypopneic patient.

All of the training sessions were supervised. Visual feedback of the subject’s ventilation and the target ventilation was provided to assist them in reaching the target. When the subject’s ventilation dipped below the target Ve, he/she was provided with verbal encouragement to reach the target.

The subjects performed hyperpneic training for 15 min initially, and this was gradually extended to 20 min. When the subjects could perform hyperpneic training for 20 min, the target ventilation was increased by 5 to 10%. During the last three exercise sessions, the target ventilation averaged 72.5 ± 3.2% of the MVV.

**Data Analysis**

**Results**

The baseline characteristics of the 29 patients who completed the protocol are shown in Table 1. Patients had moderate-to-severe airflow obstruction with air trapping. The pulmonary function and demographics of the two groups were well-matched with no significant difference for any variable between groups. As expected, pulmonary function was unchanged after pulmonary rehabilitation (data not shown).

**Training Sessions**

Compliance during the rehabilitation program was excellent, as patients missed on average only 2 of 24 sessions (range, 0 to 6 sessions). Any sessions missed were made up at the end of the 8-week program to ensure that all of the subjects completed 24 sessions of training. The average duration of cycle and treadmill exercise during each session was similar in both groups. There was significant improvement in both cycle and treadmill performance in both groups.
The rate of progression of cycle and treadmill exercise was similar in the two groups.

**Effect of Training on Respiratory Muscle Strength and Endurance**

At baseline, respiratory muscle strength and endurance were not significantly different between groups (Table 3). Pmax did not increase in either group after rehabilitation. Pmax significantly increased after training in the combined training group (p = 0.017) but not in the endurance training group. However, because Pmax did tend to increase in the endurance training group after training (p = 0.102), the difference in the extent of improvement between groups was not statistically significant (p = 0.20). Respiratory muscle endurance increased in both groups after training (endurance training group, p = 0.0051; combined training group, p < 0.0001), but the extent of improvement was significantly greater in the combined training group (p = 0.02).

**Effect of Training on Quality of Life**

There were no differences at baseline in any of the quality-of-life domains between the two groups (Table 3). Both groups had statistically and clinically significant improvement in the dyspnea domain (endurance training group, p < 0.0001; combined training group, p = 0.0002) and fatigue domain (endurance training group, p = 0.0001; combined training group, p = 0.027) after rehabilitation, but there was no difference in the extent of improvement between groups. The minimal clinically significant difference is defined as a mean improvement of 0.5 per question.24 Because there are five dyspnea questions and four fatigue questions, increases in the total domain score of 2.5 and 2 would be the minimal clinically significant difference, and these thresholds were reached in both groups. In the endurance training group, statistically and clinically significant improvements in the emotion domain (p = 0.0122) and mastery domain (p = 0.0045) were also observed, whereas these variables did not reach statistical significance in the combined treatment group, but, again, there was no difference in the extent of improvement between groups.

**Effect of Training on Exercise Performance**

At baseline, maximal exercise parameters were not significantly different between groups (Table 4). Maximal exercise capacity significantly improved in the endurance training group after rehabilitation (p = 0.0036), whereas the improvement in the combined training group after rehabilitation approached statistical significance (p = 0.07). There was no significant difference in the extent of improvement between the groups. At the same work rate, the heart rate decreased by 5% after rehabilitation in both groups, but this modest decrease did not reach statistical significance in either group.

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**Table 1**—Patient Characteristics*

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Endurance Training Group (n = 14)</th>
<th>Combined Training Group (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>70.9 ± 2.0</td>
<td>69.7 ± 2.0</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.76 ± 0.02</td>
<td>1.78 ± 0.03</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>83.5 ± 3.2</td>
<td>80.1 ± 5.9</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>26.9 ± 0.9</td>
<td>28.3 ± 2.3</td>
</tr>
<tr>
<td>FEV₁, L</td>
<td>1.44 ± 0.10</td>
<td>1.49 ± 0.16</td>
</tr>
<tr>
<td>FEV₁ % predicted</td>
<td>43.6 ± 3.5</td>
<td>45.1 ± 5.5</td>
</tr>
<tr>
<td>FVC, L</td>
<td>3.00 ± 0.17</td>
<td>2.73 ± 0.18</td>
</tr>
<tr>
<td>FVC % predicted</td>
<td>69.1 ± 4.2</td>
<td>61.7 ± 4.0</td>
</tr>
<tr>
<td>TLC, % predicted</td>
<td>114.6 ± 6.0</td>
<td>105.3 ± 4.0</td>
</tr>
<tr>
<td>RV % predicted</td>
<td>198 ± 16</td>
<td>182 ± 14</td>
</tr>
<tr>
<td>DLCO % predicted</td>
<td>59.9 ± 7.2</td>
<td>57.8 ± 8.0</td>
</tr>
<tr>
<td>MVV, L/min</td>
<td>54.8 ± 3.9</td>
<td>53.1 ± 5.1</td>
</tr>
<tr>
<td>Pao₂, mm Hg</td>
<td>79.9 ± 3.1</td>
<td>75.4 ± 2.7</td>
</tr>
<tr>
<td>Paco₂, mm Hg</td>
<td>39.1 ± 2.2</td>
<td>37.5 ± 1.3</td>
</tr>
</tbody>
</table>

*Values given as mean ± SE. Arterial blood gas levels in patients receiving supplemental oxygen were obtained while they were receiving their prescribed oxygen dose. DLCO = diffusing capacity of the lung for carbon monoxide; RV = residual volume; TLC = total lung capacity.

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**Table 2**—Training Sessions*

<table>
<thead>
<tr>
<th>Variables</th>
<th>Endurance Training Group</th>
<th>Combined Training Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First Sessions</td>
<td>Last Sessions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treadmill speed, mph</td>
<td>1.5 ± 0.1</td>
<td>2.6 ± 0.1†</td>
</tr>
<tr>
<td>Treadmill elevation, %</td>
<td>0.1 ± 0.1</td>
<td>1.2 ± 0.2†</td>
</tr>
<tr>
<td>Treadmill time, min</td>
<td>6.6 ± 0.6</td>
<td>18.7 ± 1.3†</td>
</tr>
<tr>
<td>Bike, W</td>
<td>34.4 ± 2.6</td>
<td>56.3 ± 3.6†</td>
</tr>
<tr>
<td>Bike time, min</td>
<td>11.0 ± 0.9‡</td>
<td>17.4 ± 0.5‡</td>
</tr>
</tbody>
</table>

*Values given as the mean ± SE of the first three and last three rehabilitation sessions. mph = miles per hour.
†Significant difference from first sessions, p < 0.0001.
‡Significant difference from first session, p < 0.0015.
§Significant difference between treatment groups, p < 0.03.
Combined Training Group

Effect of Training on Quadriceps Fatigability

TwQp values measured before and after exercise, prerehabilitation and postrehabilitation, are shown in Figure 1 for the endurance training group and the combined training group. In the endurance training group, the mean TwQp fell significantly after exercise prerehabilitation to a minimum of 78.0 ± 2.7% of the baseline value at 30 min after exercise. The mean TwQp fell less after exercise postrehabilitation, but this difference did not approach statistical significance. In the combined training group, the mean TwQp fell significantly after exercise prerehabilitation to a minimum value of 82.5 ± 4.3% of the baseline value at 30 min after exercise. TwQp also fell significantly after exercise postrehabilitation, but the extent of the fall was significantly less (p = 0.023).

Before rehabilitation, the fall in TwQp after exercise was similar in the two groups. The change in the extent of the fall in TwQp after exercise with rehabilitation was not significantly different for the two groups.

In the subjects in whom reliable compound motor action potentials (M waves) could be obtained, there was no change in M-wave amplitude at any time after exercise, either before or after training.

Superimposed twitches were a mean 8.6 ± 1.7% of TwQp at baseline before rehabilitation in the endurance training group and mean 9.8 ± 2.2% in the combined training group. There was no significant change in the superimposed twitch after exercise either before or after rehabilitation in either group.

### Table 3—Respiratory Muscle and Quality-of-Life Measurements*

<table>
<thead>
<tr>
<th>Variables</th>
<th>Prerehab</th>
<th>Postrehab</th>
<th>Prerehab</th>
<th>Postrehab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pimax, cm H₂O</td>
<td>65.1 ± 6.8</td>
<td>70.2 ± 6.0</td>
<td>65.4 ± 8.3</td>
<td>76.3 ± 8.4</td>
</tr>
<tr>
<td>Pmin, cm H₂O</td>
<td>110.3 ± 7.0</td>
<td>112.9 ± 6.5</td>
<td>127.0 ± 11.1</td>
<td>132.0 ± 10.7</td>
</tr>
<tr>
<td>RM endurance time, min</td>
<td>13.2 ± 1.7</td>
<td>21.8 ± 3.5†</td>
<td>10.6 ± 1.6</td>
<td>25.1 ± 2.3†</td>
</tr>
<tr>
<td>VE, % MVV</td>
<td>69.1 ± 1.8</td>
<td>70.2 ± 1.8</td>
<td>69.9 ± 2.6</td>
<td>74.5 ± 3.3</td>
</tr>
<tr>
<td>Dyspnea</td>
<td>16.9 ± 1.2</td>
<td>23.4 ± 1.7†</td>
<td>16.5 ± 0.9</td>
<td>20.7 ± 0.8†</td>
</tr>
<tr>
<td>Fatigue</td>
<td>15.1 ± 0.9</td>
<td>19.6 ± 0.9†</td>
<td>16.5 ± 1.6</td>
<td>18.9 ± 1.3†</td>
</tr>
<tr>
<td>Emotion</td>
<td>35.6 ± 2.1</td>
<td>39.3 ± 2.0†</td>
<td>34.7 ± 2.3</td>
<td>36.6 ± 2.3</td>
</tr>
<tr>
<td>Mastery</td>
<td>19.5 ± 1.1</td>
<td>22.8 ± 1.1†</td>
<td>21.1 ± 1.3</td>
<td>22.3 ± 1.3</td>
</tr>
</tbody>
</table>

*Values given as mean ± SE. prerehab = prerehabilitation; postrehab = postrehabilitation; RM = respiratory muscle.
†Significant difference from prerehabilitation value.
‡Significant difference in extent of improvement between groups.

### Table 4—Maximal Exercise Data*

<table>
<thead>
<tr>
<th>Variables</th>
<th>Prerehab</th>
<th>End Exercise</th>
<th>Isowork</th>
<th>Prerehab</th>
<th>End Exercise</th>
<th>Isowork</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workload, W</td>
<td>59 ± 4</td>
<td>67 ± 5†</td>
<td></td>
<td>57 ± 5</td>
<td>65 ± 7</td>
<td></td>
</tr>
<tr>
<td>VO₂, L/min</td>
<td>1.09 ± 0.05</td>
<td>1.14 ± 0.06</td>
<td>1.07 ± 0.08</td>
<td>1.10 ± 0.10</td>
<td>1.12 ± 0.10</td>
<td>0.99 ± 0.09</td>
</tr>
<tr>
<td>VE, L/min</td>
<td>43.8 ± 2.0</td>
<td>48.1 ± 3.2†</td>
<td>42.0 ± 2.9</td>
<td>45.1 ± 3.9</td>
<td>47.4 ± 4.1</td>
<td>41.0 ± 3.8</td>
</tr>
<tr>
<td>HR, beats/min</td>
<td>115 ± 5</td>
<td>118 ± 5</td>
<td>109 ± 5</td>
<td>126 ± 4</td>
<td>131 ± 3</td>
<td>120 ± 3</td>
</tr>
</tbody>
</table>

*Values given as mean ± SE. HR = heart rate; VO₂ = oxygen consumption. See Table 3 for abbreviations not used in the text.
†Significant difference from prerehabilitation value.
There were no significant differences in the superimposed twitch between groups or before and after rehabilitation in either group.

**Discussion**

The major findings of this study were as follows: (1) the addition of hyperpneic training to an endurance exercise program led to improvements in respiratory muscle endurance in patients with COPD beyond those achieved by endurance training alone; and (2) this improvement in respiratory muscle endurance did not translate into additional improvement in endurance exercise performance or quality of life compared with that achieved by an endurance exercise program alone.

**Effects of Hyperpneic Training on Respiratory Muscle Endurance and Strength**

Patients who underwent standard endurance exercise training demonstrated an improvement in respiratory muscle endurance. As expected, the hyperpneic training sessions led to a significantly greater improvement in respiratory muscle endurance than that achieved by endurance exercise alone. Thus, the hyperpneic training regimen was sufficient to train the respiratory muscles. Patients in the combined training group also demonstrated a significant increase in maximal inspiratory strength after training (absolute increase of 11 cm H_2O compared with baseline), although the difference between groups did not reach statistical significance, because the endurance group also tended to increase maximal inspiratory strength after training, but to a smaller extent (absolute increase of 5 cm H_2O). Thus, whether a combined training regimen can produce a greater increase in inspiratory strength than endurance training alone needs to be evaluated in a larger group of patients.

In a prior study of hyperpneic training, patients with COPD trained for 30 min a day, 5 days a week for 8 weeks with no additional exercise training. This is clearly a more intense regimen than the one used in our study. Because our subjects were also performing concurrent endurance exercise, we reduced the amount of hyperpneic training to 15 to 20 min a day, 3 days a week for 8 weeks. In preliminary pilot studies, we found that performing hyperpneic training for greater periods of time during the same session as the endurance training appeared to tire the patients and made endurance training more difficult. Despite this reduction in the intensity of training, patients in the combined training group were still able to achieve substantially larger improvements.

**Table 5—Endurance Exercise**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Endurance Training Group</th>
<th>Combined Training Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prerehab</td>
<td>Postrehab</td>
</tr>
<tr>
<td>Endurance time, min</td>
<td>9.0 ± 1.5</td>
<td>25.8 ± 3.6†</td>
</tr>
<tr>
<td>V̇O_2, L/min</td>
<td>1.09 ± 0.07</td>
<td>1.19 ± 0.08</td>
</tr>
<tr>
<td>HR, beats/min</td>
<td>114 ± 6</td>
<td>117 ± 6</td>
</tr>
<tr>
<td>V̇E, L/min</td>
<td>44.4 ± 2.4</td>
<td>45.7 ± 3.6</td>
</tr>
<tr>
<td>V̇T, L</td>
<td>1.53 ± 0.07</td>
<td>1.52 ± 0.08</td>
</tr>
<tr>
<td>Fb, breaths/min</td>
<td>31.7 ± 1.2</td>
<td>34.7 ± 1.3†</td>
</tr>
</tbody>
</table>

*Values given as mean ± SE. Fb = respiratory rate; V̇T = tidal volume. See Tables 3 and 4 for abbreviations not used in the text.
†Significant difference from prerehabilitation value.
provements in respiratory muscle endurance than patients in the endurance training group. However, it is quite likely that greater improvement would have been achieved had we performed a more intense hyperpneic regimen. In the prior study, expiratory muscle strength was also increased after hyperpneic training. We did not observe any increase in expiratory muscle strength, and this may well reflect the difference in exercise intensity.

Our study did not determine the mechanism whereby hyperpneic training increased respiratory muscle endurance. A previous study has shown that threshold loading was capable of inducing structural changes within the muscle in patients with COPD. An increase in the proportion of type I fibers and the size of type II fibers was seen in the external intercostal muscle. Oxidative enzyme capacity was not measured. Whether hyperpneic training, as delivered in this study, is capable of inducing structural changes within the respiratory muscles will need to be determined in future studies. Other potential mechanisms for the improvement in our measure of respiratory muscle endurance would include perceptual adaptation to hyperpnea (i.e., dyspnea desensitization) and/or increased efficiency in performing the maneuvers with repeated practice.

Effect of Hyperpneic Training on Exercise Performance and Quality of Life

Combined training did not result in any incremental improvement in exercise performance or quality of life compared with endurance training alone. Although the number of patients studied was relatively modest, there was no tendency for any measure of exercise performance to improve with combined therapy. Similar results have been obtained with inspiratory muscle-resistive or threshold-load training. Because normocapnic hyperpnea may more closely mimic the load faced by the respiratory muscles during exercise, it could be a qualitatively better training stimulus than resistive or threshold breathing. Thus, we had hoped that it would provide additional improvement in exercise performance. Prior studies comparing hyperpneic training to a control group demonstrated in most studies that hyperpneic training was capable of improving exercise performance and quality of life. However, our study is the first to look at whether hyperpneic training can additionally augment the improvement seen with endurance training.

A metaanalysis of inspiratory muscle training using resistive and threshold loading suggested that training was more effective in subjects with inspiratory muscle weakness (defined as a Pmax of < 60 cm H2O), and there was a suggestion that inspiratory muscle training in such patients might augment functional exercise capacity. Nine of the 15 patients in our study who underwent combined training had Pmax values of < 60 cm H2O. There was no significant difference in the extent of improvement after training in 6-min walk distance, peak exercise capacity, and endurance exercise time in those with and without inspiratory muscle weakness. In the metaanalysis, it was also suggested that inspiratory muscle training might be more effective in patients who had ventilatory limitation during exercise. In our study, the mean V˙E/MVV ratio in the combined group was 80.3 ± 3.3%. Nine of the 15 subjects had a V˙E/MVV ratio of > 80%. There was no significant difference in the extent of improvement after training in 6-min walk distance, peak exercise capacity, and endurance exercise time in those with and without a ventilatory limitation to exercise. Our study was a short-term study and did not address potential long-term effects.

It is possible that improving respiratory muscle endurance could help patients during subsequent acute exacerbations of their disease, potentially reducing morbidity or even mortality. However, like all exercise interventions, the subjects would have to continue with a maintenance program in order to sustain the benefits in respiratory muscle endurance seen with hyperpneic training. Finally, some patients with COPD are too disabled to effectively perform endurance exercise, and in these patients, hyperpneic training might still provide useful benefits. Additional studies comparing the results of respiratory muscle endurance training alone with endurance exercise training might address this latter issue.

Comparison to Healthy Subjects

Although such findings are still contentious, some studies have shown that hyperpneic training can augment endurance exercise performance in healthy subjects. Improvements in endurance exercise performance were seen in both sedentary nonexercising subjects and competitive endurance athletes. Not surprisingly, no improvements were seen in maximum exercise capacity. Why then were benefits not seen in patients with COPD? Healthy subjects, if they exercise intensely enough, can develop diaphragmatic fatigue. In contrast, patients with COPD who exercise to the limits of tolerance rarely develop diaphragmatic fatigue. The reason why patients with COPD do not develop fatigue is not totally clear but may reflect the following concepts: (1) mechanical restraints limit exercise performance before the functional limits of the diaphragm are met; (2) the disease itself trains the diaphragm and increases its fatigue resistance (e.g., from an increased
proportion of fatigue-resistant fibers and increased oxidative capacity; (3) the muscle is forced to contract at a short length because of hyperinflation, which increases fatigue resistance; and/or (4) the limited rise in transdiaphragmatic pressure does not impede diaphragmatic blood flow. Perhaps the prevention of diaphragmatic fatigue by hyperpneic training allows healthy subjects to exercise longer. In patients with COPD, this potential mechanism would not be operative.

**Effect of Hyperpneic Training on Limb Muscle Fatigability**

In the combined training group, quadriceps fatigability was significantly reduced after training. In contrast, quadriceps fatigability was not significantly reduced after training in the endurance group alone. However, the extent of improvement with training was not significantly different between groups, because there was modest improvement with training in the endurance group as well. A reduction in quadriceps fatigability would be expected to improve endurance exercise performance, because fatigue of the quadriceps muscle appears to limit high-intensity, constant-workload-cycle exercise in a significant proportion of patients with COPD. Because we did not find any additional improvement in endurance exercise with combined training, this suggests that there was no real difference in quadriceps fatigability between groups.

In conclusion, hyperpneic training, when added to a program of endurance training, significantly augments respiratory muscle endurance, but this improved endurance does not translate into additional improvements in quality of life or exercise performance.

**Acknowledgment:** We thank Raymond Carter, LPN, for his help with the exercise training program, and Rosemary Cieslak for her secretarial support.

**References**


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