CLINICAL INVESTIGATIONS

Exercise Training: Therapy for Patients with Chronic Obstructive Pulmonary Disease*

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Eleven patients with chronic obstructive pulmonary disease completed an 18-week program of exercise training with subjective and objective improvement. Increased activities of daily living were noted by these patients and substantiated by analysis of exercise diaries. Resting and exercise heart rate decreased, and maximum tolerated work load increased significantly in all patients. Alterations of physiologic measurements produced by ventilation/perfusion abnormalities or infection invalidated \( V_\text{O}_2 \) as a gauge of successful training; these factors did not limit successful training.

Chronic obstructive pulmonary disease is a leading cause of morbidity and mortality in the United States; effective therapy for afflicted patients is limited.1,2 Preventive measures, such as discontinuation of smoking and proper use of antibiotics to prevent and treat respiratory tract infection, can help to preserve existing function; mucolytic and expectorant agents help those patients who cough effectively.

Shortness of breath limits the activity of these patients, and the resultant lack of activity leads to an unfit state and increased dyspnea; a vicious cycle emerges.

Subjective improvement has been reported by the few advocates of graded exercise training for patients with chronic obstructive pulmonary disease; however, objective measurements of improvement have been inconclusive.3,4 This program of graded exercise training was undertaken to analyze the mechanisms of improvement and possible limiting factors of successful training.

METHODS

Twelve patients with chronic obstructive pulmonary disease were selected from a larger group as candidates for exercise training after screening with history, including the MRC respiratory disease questionnaire,5 physical examination, and pulmonary function tests. Prerequisites for inclusion in the program were symptomatic chronic obstructive pulmonary disease with dyspnea while walking at an ordinary pace on level ground or on washing or dressing, and motivation to lead a more active life. Patients were not excluded because of advanced age. All had smoked at least a package of cigarettes a day for 20 years, but had discontinued smoking prior to entering the program (Table 1).

After the patients were in optimal health without the use of exercise, they were admitted to the Clinical Center of Peter Bent Brigham Hospital for baseline evaluation. Measurements of pulmonary function included the subdivisions of total lung capacity by spirometry and helium dilution. The time of equilibration with helium in a closed circuit was measured and expressed as mixing efficiency.6 Maximum voluntary ventilation,7 steady state diffusing capacity,8 and maximal inspiratory and expiratory flow rates were measured.9 Studies were performed in the erect position, and the results were compared to normal standards.10,11

Patients were seated on a bicycle ergometer, breathing room air through a two-way, high velocity, low resistance valve, the inlet of which was connected to a Parkinson-Cowan dry gas meter to facilitate continuous measurement of minute ventilation. After 30 minutes of rest to achieve steady state, exercise was initiated and continued for six minutes against a preselected and constant work load.12 Minute ventilation, heart rate, oxygen consumption, and carbon dioxide production were continuously recorded throughout the 30 minutes of rest and six minutes of exercise. Studies were repeated each day of the initial week to

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**EXERCISE TRAINING IN CHRONIC OBSTRUCTIVE PULMONARY DISEASE**

**Table 1—Clinical Data of Patients Studied**

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age</th>
<th>Sex</th>
<th>Diagnoses*</th>
<th>Smoking History</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>75</td>
<td>M</td>
<td>Emphysema, Chronic bronchitis, Bronchospasm, Left heart failure</td>
<td>2-3 pks/day x 42 yrs</td>
</tr>
<tr>
<td>2</td>
<td>68</td>
<td>M</td>
<td>Chronic bronchitis, Emphysema, Recurrent pneumonia</td>
<td>2 pks/day x 41 yrs</td>
</tr>
<tr>
<td>3</td>
<td>67</td>
<td>M</td>
<td>Emphysema, Chronic bronchitis</td>
<td>1 pk/day x 40 yrs</td>
</tr>
<tr>
<td>4</td>
<td>67</td>
<td>M</td>
<td>Emphysema, Chronic bronchitis, Bronchospasm</td>
<td>1 pk/day x 50 yrs</td>
</tr>
<tr>
<td>5</td>
<td>67</td>
<td>M</td>
<td>Emphysema, Chronic bronchitis, Bronchial asthma, Left heart failure</td>
<td>1½ pks/day x 40 yrs</td>
</tr>
<tr>
<td>6</td>
<td>64</td>
<td>M</td>
<td>Emphysema, Chronic bronchitis</td>
<td>1 pk/day x 50 yrs</td>
</tr>
<tr>
<td>7</td>
<td>64</td>
<td>M</td>
<td>Emphysema, Left heart failure</td>
<td>1 pk/day x 40 yrs</td>
</tr>
<tr>
<td>8</td>
<td>63</td>
<td>M</td>
<td>Emphysema, Chronic bronchitis, Bronchospasm</td>
<td>2 pks/day x 25 yrs</td>
</tr>
<tr>
<td>9</td>
<td>60</td>
<td>M</td>
<td>Chronic bronchitis, Emphysema, Left heart failure</td>
<td>1 pk/day x 40 yrs</td>
</tr>
<tr>
<td>10</td>
<td>57</td>
<td>M</td>
<td>Bronchial asthma, Emphysema, Chronic bronchitis</td>
<td>1-3 pks/day x 42 yrs</td>
</tr>
<tr>
<td>11</td>
<td>43</td>
<td>M</td>
<td>Chronic bronchitis, Bronchiectasis</td>
<td>1 pk/day x 20 yrs</td>
</tr>
<tr>
<td>12</td>
<td>42</td>
<td>F</td>
<td>Emphysema, Chronic bronchitis, Bronchospasm</td>
<td>1 pk/day x 25 yrs</td>
</tr>
</tbody>
</table>

*Diagnoses are listed in the order of their relative importance for each patient.

†PTP—prior to program

Scores were tabulated each day and averaged for each week. The percentage change in score was compared to the initial week of training (Fig 1).

Results

Eleven of the 12 patients completed the program and claimed they could “do more” with less shortness of breath. Patient 2 (Table 1) had recurrent episodes of bronchopneumonia and discontinued exercise after the initial studies. Analysis of diaries for patients completing the program showed that all had increased their activity of daily living. Diary analysis for patient 1 is shown in Figure 1. The other patients had similar records.

Patients completing the program had a significant
Emphysema accounts for 7 percent of disability pensions, and together with other bronchopulmonary disorders, accounts for 1.6 percent of annual deaths. Bronchopulmonary disorders are numerous and precise diagnosis must be established for proper therapy.

Emphysema, chronic bronchitis, and bronchial asthma are different pathophysiologic processes which often coexist. Emphysema is an anatomic alteration of the lung characterized by an abnormal enlargement of air spaces distal to the terminal nonrespiratory bronchiole and accompanied by destructive changes of alveolar walls. Chronic bronchitis is a clinical disorder characterized by excessive mucous secretion in the bronchial tree and manifested by chronic or recurrent productive cough which should arbitrarily be present on most days for a minimum of three months in the year and for not less than two successive years. Bronchial asthma is both an acute and chronic disease characterized clinically by episodes of shortness of breath and wheezing with symptom-free intervals of varying lengths. Bronchial asthma should be differentiated from bronchospasm, a loose term which is used to describe a "wheezy chest," a sign which can be present in all forms of chronic obstructive pulmonary disease or in left heart failure. Left heart failure in this report means an elevation of left ventricular end-diastolic pressure and an associated increase in interstitial fluid in the lung. Clinically, this is characterized by shortness of breath and wheezing and often is called "cardiac asthma."

Shortness of breath is the symptom which most often brings patients with chronic bronchitis, emphysema, and left heart failure to physicians. A sudden increase in the severity of dyspnea in these patients was observed in our study. This symptom is often associated with an increase in exercise requirements and a decrease in the person's ability to perform activities of daily living. The increase in exercise requirements was reflected in the patient's report of increased air intake during physical activity and the need for supplemental oxygen.

The table below shows the results of the exercise training program for a sample patient.

Table 2—Sample Page of Diary, Patient No. 1

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Tension</th>
<th>Pedometer Reading</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/1/69</td>
<td>15 Min</td>
<td>1</td>
<td>3.2</td>
<td>Walked 2 flights of stairs first</td>
</tr>
<tr>
<td></td>
<td>15 Min</td>
<td></td>
<td></td>
<td>time in 6 years</td>
</tr>
<tr>
<td>2/2/69</td>
<td>15 Min</td>
<td>1</td>
<td>3.5</td>
<td>Went out shopping</td>
</tr>
<tr>
<td></td>
<td>15 Min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2/3/69</td>
<td>15 Min</td>
<td>1</td>
<td>3.5</td>
<td>Went to movies</td>
</tr>
<tr>
<td></td>
<td>10 Min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2/4/69</td>
<td>15 Min</td>
<td>1.5</td>
<td>3.3</td>
<td>Rode bike moderate distance</td>
</tr>
</tbody>
</table>
patients was often caused by an attack of acute asthma or infection. Infection itself often precipitated bronchial asthma or left heart failure.

It is possible to claim that the decrease in dyspnea noted by our patients was psychological. Indeed, exercise can have a positive psychological effect; however, objective measurements of improvement accompanied the subjective claim of these patients. Increase in the activity of these patients was evident in calculated diary scores (Fig 1). Patients and physicians found the diary valuable; patients claimed that it served as an incentive to perform increased amounts of exercise, and physicians felt that it was a valuable tool to quantify home performance. A decrease in the weekly diary score was often an early sign of intercurrent infection or a clue that the patient had not kept up with his program.

The most sensitive gauge of training and of good health in these patients was the magnitude of decrease in heart rate from the initial level both at rest and during exercise. After achieving the trained state, an increase in the resting heart rate proved to be the harbinger of an acute respiratory infection or of other illness. During the 18 weeks of training, none of the patients had a heart rate as high as the pretraining rate even in the presence of an intercurrent illness.

The maximum work load achieved on subsequent visits increased for the 11 patients completing the program. After training, interruption of exercise for short intervals was associated with a decrease in the maximal work load achieved at the next laboratory visit; however, the maximal load never fell as low as the pretraining level.

$V_{\text{E}}O_2$ is often used as a gauge of training. It is dependent on the determinants of oxygen consumption and minute ventilation. Changes in $V_{\text{E}}O_2$ were variable for different patients in this series; in many, the magnitude and direction of change could be accounted for by factors other than training. If patients had bronchospasm at the time of an exercise study, there would be a greater increase in minute ventilation than in oxygen consumption with a resultant increase in $V_{\text{E}}O_2$. The increased bronchospasm was evident by history and on physical examination and was reflected in pulmonary function tests by an increase in dead space breathing. Increased ventilation of dead space could account for the increased minute ventilation of these patients. Patients 3, 4, 8, and 10 (Table 1 and Fig 5, 6) had increased bronchospasm
Chronic obstructive pulmonary disease alone or coexisting with left heart failure, and left heart failure in normal lungs are associated with ventilation/perfusion abnormalities. During normal breathing in the erect lung ventilation per unit volume is greatest at the lung bases and least at the apices; conversely, physiologic dead space is greatest in the upper and least over the lower lobes. In the normal upright lung, the occurrence of left heart failure leads to selective transudation of fluid into the interstitial and alveolar spaces of the lower lobes. The resultant increase in interstitial pressure and edema fluid narrows small airways and secondarily causes a ventilation shift away from the lower to the upper lobes where there is larger physiologic dead space.

In the erect position there is a zonal distribution of blood flow within the lungs, the apices receiving the least and the bases the largest amount of perfusion. Factors regulating the distribution of blood flow within the lungs are multiple and include pulmonary arterial and venous pressure and alveolar pressure. With left heart failure, hydrostatic forces produce a relatively higher venous pressure in the lower compared to the upper lobes. Transudation occurs selectively at the lung bases producing a regional increase in interstitial pressure and secondarily a diminished retractile force on the walls of the extraalveolar vessels which close by virtue of their inherent tonus. The resultant increase in pulmonary vascular resistance leads to reduction of blood flow through the lower lobes with redistribution to the upper lobes.

Four patients in this study had ventilation/perfusion abnormalities secondary to coexisting chronic obstructive pulmonary disease and left heart failure. In the erect position, patients 1 and 7 (Table 1) had good perfusion at the lung bases; however, ventilation was best at the apices. The resultant ventilation/perfusion abnormality was associated with a high oxygen consumption and a low $V_{E02}$. With the occurrence of left heart failure, redistribution of perfusion away from the bases to the well-ventilated apices took place. The resultant improvement in ventilation/perfusion relationships was associated with a fall in oxygen consumption, an elevation of $V_{E02}$, and a decrease in dead space ventilation. In these patients decreased oxygen consumption with the occurrence of left heart failure could have been related to the decreased oxygen cost of breathing secondary to the better ventilation/perfusion relationships. Left heart failure in patients 5 and 10 (Table 1) was associated with a greater perfusion than ventilation shift away from the lung bases to the apices and an increase in ventilation/perfusion abnormality and dead space ventilation. Oxygen consumption increased and $V_{E02}$ decreased.

In these four patients, change in $V_{E02}$ was related more to the patient's cardiac status than to exercise training, and the directional change in oxygen consumption and in $V_{E02}$ was dependent on the regional location of the pulmonary disease and the directional change in dead space ventilation.
EXERCISE TRAINING IN CHRONIC OBSTRUCTIVE PULMONARY DISEASE

It is possible to hypothesize that patients with only emphysema or chronic bronchitis have a decrease in $V_{5O_2}$ after training due to improvement in chest wall mechanics and the resultant improvement in ventilation/perfusion relationships which might accompany this. All patients completing our program had significant improvement in their inspiratory capacity and maximal voluntary ventilation at the 18th week. Changes in the other indices of pulmonary function were not significant for the group; however, changes occurring in individual patients helped to quantify the presence and degree of either bronchospasm or left heart failure at the time of each exercise study. 17

Although bronchospasm and left heart failure obviated the use of $V_{5O_2}$ as a gauge of training, they were not limiting factors to successful exercise training. Subjective and objective improvement seemed to correlate with motivation of the patient to lead a more active life. The physiologic index easiest to follow and correlating best with improvement after training was heart rate, both at rest and during exercise, a lower heart rate indicating a fit state.

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REFERENCES


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