Target-Flow Inspiratory Muscle Training during Pulmonary Rehabilitation in Patients with COPD*

P. N. Richard Dekhuijzen, M.D., Ph.D.; Hans Th. M. Folgering, M.D., Ph.D.; and Cees L. A. van Herwaarden, M.D., Ph.D.

The effects of additional target-flow inspiratory muscle training (TF-IMT) on the performance of the inspiratory muscles, on general exercise capacity, and on psychologic parameters during a pulmonary rehabilitation program (PR) were studied in 40 patients with COPD selected for ventilatory limitation during exercise. The mean age of the patients was 59 years, and the mean FEV1, was approximately 50 percent of predicted. All patients participated in a ten-week PR program. They were randomized to receive either additional TF-IMT (PR + IMT) or not (PR). The TF-IMT was performed by means of a target-flow resistive device; the generated mouth pressure and the duration of inspiration and of the respiratory cycle were imposed. After the training period, maximal inspiratory mouth pressure and EMG-fatigability of the diaphragm were significantly better in the PR + IMT group than in the PR group.

Maximal work load and psychologic symptoms increased to the same extent in both groups. The 12-minute walking distance also increased in both groups, but it increased significantly more in the PR + IMT group than in the PR group. We believe that additional TF-IMT during PR in a selected group of patients with COPD who have ventilatory limitation has an extra beneficial effect on the performance of the inspiratory muscles and on exercise performance.

(IMT = inspiratory muscle training; PR = pulmonary rehabilitation; TF-IMT = target-flow IMT; Fc = centroid frequency; tgcFe = tangent of Fc/time; FDia = Fc of the power spectrum of the diaphragm; FJC = Fc of the power spectrum of the intercostal muscles; Tens = endurance time of static inspiratory maneuvers; ADL = activities in daily life; SCL-90 = symptom checklist; MWU = Mann-Whitney U test)

Inspiratory muscle training (IMT) in patients with chronic obstructive pulmonary disease (COPD) can result in an increase of strength and endurance of these muscles. The effects of IMT on the general exercise capacity of these patients, however, are controversial. Some investigators found an increased exercise capacity after IMT, whereas other studies did not reveal such effects. This bias may be due to an inadequate selection of patients who underwent IMT or to the method and protocol of IMT. Furthermore, the effects of additional IMT during a pulmonary rehabilitation (PR) program have not been studied yet (to our knowledge). The aim of this study is to investigate whether additional supervised target-flow IMT (TF-IMT) during PR is superior to PR alone in patients with COPD with ventilatory limitation of their exercise capacity in terms of performance of the inspiratory muscles, general exercise capacity, and psychologic symptoms.

**METHODS**

*Design of the Study*

Forty patients with COPD selected because of ventilatory limitation of their exercise capacity participated in a ten-week PR program. Before entering, they were randomly assigned to either receive or not receive additional TF-IMT. Measurements of inspiratory muscle performance, exercise capacity, and psychologic symptoms were made before entering the program, after four weeks, and at the end of the training programs. Informed consent was obtained from all patients. The protocol was approved by the local Ethical Committee.

*Patients*

Patients with functional limitations due to COPD were selected from the outpatient clinic. The characteristics of the patients are shown in Table 1. All patients had moderate to severe airflow obstruction without significant changes after inhalation of bronchodilators.

In all of them, a ventilatory limitation of the exercise capacity was established by means of a maximal bicycle ergometer test. All patients stopped the exercise test because of dyspnea and muscle fatigue of the legs.

The ventilatory limitation was defined as a normal resting arterial PCO2 that rose during progressive exercise. This may indicate an insufficiency of the respiratory muscles to maintain an adequate ventilation during the higher metabolic rate of exercise. As the alveolar-arterial oxygen pressure difference (P[A-a]O2) increases with 1.5 to 2 kPa during progressive exercise in normal subjects, an additional selection criterion was that the P[A-a]O2 did not increase by more than 2 kPa at maximal exercise. In this way, patients were excluded who had severe lowering of the arterial PO2 due to ventilation-perfusion mismatching, or with diffusion or shunt phenomena during exercise. There were no other limitations of the exercise capacity in these patients, such as cardiovascular or neuromuscular problems.

*Training*

**Pulmonary Rehabilitation Program:** For a period of ten weeks, all patients participated in the outpatient PR program, five days a

---

*From the University of Nijmegen, Department of Pulmonary Diseases, Medical Centre Dekkerswold, Groesbeek, the Netherlands.

Manuscript received February 28; revision accepted June 11.

Reprint requests: Dr. Dekhuijzen, University of Nijmegen, PO Box 9001, Groesbeek, The Netherlands 6900 GB
week, two hours every day. This program consisted of exercise training, i.e., cycling, walking, and training of back, shoulder, and abdominal muscles. The intensity of the exercise training was determined by the symptoms of the patients. Moreover, the heart rate during these exercises did not exceed 80 percent of the maximal heart rate reached during the maximal bicycle ergometer test. Other parts of the PR program were calisthenics, conventional physiotherapy (breathing retraining, relaxation exercises), and education about the pulmonary disease and the purpose and use of the medications.

**Target-Flow Inspiratory Muscle Training:** In addition to the PR program, 20 patients participated in a specific training program for the inspiratory muscles. An incentive flowmeter (Inspir, Intertech Resources Inc) with an added resistance was used for TF-IMT.

The patients were instructed to generate an inspiratory flow rate at which the ball in the flowmeter reached the top of the device (the target-flow). The adjustable leak in the flowmeter was set by the physiotherapist, so that the patient had to generate 70 percent of his maximal inspiratory mouth pressure (Plmax) to keep the ball at the top of the flowmeter. The duration of the inspiration was set at 3 s by means of a metronome, the (unloaded) expiration at 4 s. The respiratory frequency, therefore, was eight to nine breaths per minute.

The patient performed TF-IMT during 15 minutes twice a day, supervised by the physiotherapist. Twice a week, Plmax was measured and the target-flow was adjusted to the new Plmax.

**Measurements**

**Lung Function:** Lung function measurements were made before the training period, and after four and ten weeks of training. Total lung capacity (TLC) was measured by means of the closed circuit helium-dilution method (Pulmonet III, Gould-Godart). Spirometry was performed with a wet spirometer (Pulmonet III).

**Bicycle Ergometer Test:** A maximal incremental exercise test until exhaustion was performed on an electrically braked bicycle ergometer (Lode). An estimation of the maximal work load (Wmax, watts) was made by the following equation: Wmax predicted = 1.7 × weight (kg) + 40 × FEV₁, L = 25.**11 Every minute the work load was increased by 10 percent of the predicted Wmax. Heart rate and peripheral oxygen saturation were monitored with a pulse oximeter (Oxyshuttle, SensorMedics). An arterial blood sample for blood gas analysis (Ciba Corning 178 DMS) was taken every 3 minutes and at Wmax. Every 30 s, an output was printed of minute ventilation (Ve), O₂ uptake (V̇O₂), CO₂ output (V̇CO₂), and derived parameters (Coxon IV, Mijnhardt).

**Twelve-minute Walking Distance:** This test was performed in a hospital corridor. The patients were instructed to walk as long as possible during a period of 12 minutes.**18 During the test, they were continuously encouraged to reach a maximal walking distance.**18 Before entering the study, the patients completed one 12-minute walking test to become familiar with this test.

**Maximal Inspiratory Mouth Pressure:** The Plmax from residual volume was measured by means of a flanged occluded mouthpiece, with a small leak, connected to a manometer (Validyne). Measurements were repeated until three consecutive values were within 10 percent of each other. The highest value was taken as Plmax.

**Electromyogram (EMG):** Standard surface electrodes (diameter, 5 mm) with conducting gel were used for the recording of the myoelectric activity of the diaphragm and the intercostal muscles. For the diaphragm, the electrodes were placed in the sixth and seventh intercostal spaces on the right anterior axillary line.**14 The intercostal electrodes were placed in the second and third left intercostal spaces, 2 cm from the edge of the sternum. To minimize disturbances of nonrespiratory muscles, the patients were in a semirecumbent position with appropriate support for their arms.

The EMG signals were amplified 3,000 to 10,000 times (Tonnesen amplifier) and subsequently passed through a band-pass filter of 10 to 400 Hz. To minimize the influence of the electrocardiogram, especially the QRS complex, samples of 250 ms were taken 100 ms after the detection of a QRS complex.**19

A Fourier analysis of the EMG signal provides a histogram of the contribution of the various frequencies to the total electrical power of the EMG.**16 The peak of this histogram is the centroid frequency (Fc). As a muscle fatigues, the contribution of the lower frequencies to the total power increases. As a result, Fc decreases. The rate of decline per unit of time (seconds) can be quantified by the tangent of Fc/time (tgFc) and can be used as an EMG-derived parameter of muscle fatigue.**17 The more negative tgFc, the faster a muscle fatigues.

With each sample, Fc of the power spectrum of the diaphragm (F,DIA) and the intercostal muscles (F,IC) was calculated.

**Endurance Test of the Inspiratory Muscles:** After measuring Plmax, the patients were instructed to make static inspiratory maneuvers into an almost occluded mouthpiece, which was connected to the manometer (Validyne). A small leak prevented the patients from using their buccal muscles for generating negative pressures. During these maneuvers, the patients had to keep their mouth pressure at 70 percent of their actual Plmax (the target pressure) during 8 s. The patients could control the generated mouth pressure by means of a visual feedback system. Each static inspiratory maneuver was followed by normal breathing during 22 s. During each static inspiratory maneuver, the mean value of three EMG samples after three consecutive QRS complexes was taken to calculate F,DIA and F,IC.

The endurance test was terminated when (1) the generated pressure decreased more than 20 percent during two consecutive inspiratory maneuvers, or (2) when the duration of the total endurance test was 10 minutes (ie, after 20 inspiratory maneuvers).

The results of the endurance test are presented as (1) the cumulative endurance time of the static inspiratory maneuvers (Tₐₘ, seconds), and (2) the rate of change of the F,DIA and F,IC per second (tgF,DIA and tgF,IC, expressed in Hz/s).

**Questionnaires:** The patients completed two questionnaires: an Activities in Daily Life (ADL) list with items with regard to (subjective) ability of the patient to perform daily activities: the higher these scores (0 to 11), the better the patient could perform these activities; and the Symptom Checklist (SCL-90), comprising items related to anxiety, depression, and physical complaints; values for a normal population are available, with correction for sex.**19

**Data Analysis**

The baseline parameters of the two groups were compared by means of the Wilcoxon test. The changes during the training period within one group were also compared with the Wilcoxon test. Differences in response to treatment between the two groups were analyzed by means of the Mann-Whitney U test (MWU).

<table>
<thead>
<tr>
<th>Table 1 — Patient Characteristics*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Age, yr</td>
</tr>
<tr>
<td>Sex, M:F</td>
</tr>
<tr>
<td>Height, m</td>
</tr>
<tr>
<td>Weight, kg</td>
</tr>
<tr>
<td>FEV₁, %pred</td>
</tr>
<tr>
<td>FRC/TLC, %pred</td>
</tr>
<tr>
<td>TLC, pred</td>
</tr>
</tbody>
</table>

*Values are means ± SD. Predicted values are derived from Quanjer.* PR = pulmonary rehabilitation; IMT = inspiratory muscle training.

CHEST / 99 / 1 / JANUARY, 1991 129

Downloaded From: http://journal.publications.chestnet.org/ on 11/26/2012
RESULTS

All selected patients completed the study. There were no significant differences between the two groups with regard to age, sex distribution, body measures, and pulmonary function indices (Table 1). Pulmonary medications were not changed during the study period. Also, there were no changes in static or dynamic lung volumes before and after the training period. After the training, Plmax increased in both groups (p<0.01) (Fig 1). Additional TF-IMT resulted in a significantly greater increase compared with the group without additional TF-IMT (p<0.001).

The endurance time (T_{im}) during the endurance test increased in both groups (p<0.01), with no significant differences between the two groups (Table 2). The reasons for terminating the endurance test are also listed in Table 2. Although there were more patients in the PR + IMT group than in the PR group who were able to sustain the target pressure for ten minutes, these differences were not statistically significant.

The decrease of the centroid frequency per second of the diaphragm (tgF,DIA) improved in both groups, but in the PR + IMT group, this improvement was more pronounced than in the PR group (p<0.05) (Fig 2). There was no change in the rate of decline of the centroid frequency of the intercostal muscles (tgF,IC) in either of the groups (Fig 3). It should be noted, however, that T_{im}, tgF,DIA, and TgF,IC were measured during static inspiratory maneuvers at 70 percent of the actual Plmax. This means that after ten weeks, the PR + IMT group performed the endurance test at a significantly higher PI than the PR group. Therefore, a pressure/endurance-time product was calculated by multiplying the created PI (70 percent of Plmax) by T_{im} to compare the work capacity of the inspiratory muscles between the two groups (Fig 4). In the PR group, the mean pressure-time product increased from 481 kPa.s at the start of the study to 715 kPa.s after ten weeks. In the PR + IMT group, the pressure-time product increased from 471 to 885 kPa.s, which was significantly more than in the PR group (p<0.01, MWU test).

The data of the exercise tests before and after the training period are summarized in Table 3. The 12-minute walking distance improved in both groups, but it improved significantly more in the PR + IMT group than in the PR group (p<0.05, MWU test). In both groups, maximal work load on the bicycle ergometer, VO_{2max}, and VCO_{2max} at maximal exercise, and VEmax increased significantly. For all these changes, there were no significant differences between the two groups. The heart rate at maximal exercise remained unchanged during the training period, indicating a real training effect.

Baseline PaCO_{2}, as well as the increase in PCO_{2} during the exercise test, was not changed after the training period (Table 4).

The ADL scores increased in both groups to the same extent (Table 5). Baseline scores on anxiety,
FIGURE 2. Changes of the rate of decline of the centroid frequency of the diaphragm (tgFcDIA) during the endurance test in the pulmonary rehabilitation (PR) group (filled bars) and in the PR+IMT (PR+inspiratory muscle training) group (hatched bars). Asterisk, compared with baseline: *p<0.05; two asterisks, **p<0.01; circle, PR+IMT compared with PR: p<0.05.

FIGURE 3. Changes of the rate of decline of the centroid frequency of the intercostal muscles (tgFcIC) during the endurance test in the pulmonary rehabilitation (PR) group (filled bars) and in the PR+IMT (PR+inspiratory muscle training) group (hatched bars).

FIGURE 4. Changes of the pressure-time (P-T) product during the training period in the pulmonary rehabilitation (PR) group and the PR+IMT (PR+inspiratory muscle training) group. P-T product: (0.7PImax) x (Tim).

DISCUSSION

The performance of the inspiratory muscles, the general exercise capacity, and psychologic parameters in these patients with COPD with ventilatory limita-
Inspiratory muscle performance was not the limiting factor of the exercise capacity.

The most effective method of IMT has not yet been established. Normocapnic hyperpnea has been shown to increase the endurance of the inspiratory muscles in patients with COPD. This resulted in an increase in the 12-minute walking distance and in arm and leg exercise. This training method, however, can be applied only in the laboratory because of the necessary technical facilities.

Resistive breathing has often been used to train the inspiratory muscles. To improve the performance of these muscles, a target inspiratory flow or pressure has to be defined, as well as the duration of the inspiration and expiration. If these parameters are not defined, the patients can easily adopt a nonfatiguing breathing pattern with a low inspiratory flow rate. In that case, the inspiratory muscles are not exposed to a considerable work load and will hardly be trained. This may contribute to the conflicting results of IMT. Changes in the breathing pattern during resistive breathing may be prevented by using a pressure threshold device. In this way, a threshold inspiratory pressure has to be generated to create an inspiratory airflow. Other investigators used a target-pressure device with feedback on the generated inspiratory pressure and the inspiratory and expiratory duration. Similar principles were also included in our training method. An incentive flowmeter is considerably less expensive than a manometer.

It is not clear which target pressure, expressed as a percentage of PImax, is the most effective. Other investigators used 30, 50, or 60 percent of PImax. We used a target-pressure of 70 percent of PImax, combined with an inspiration of 3 s and an expiration of 4 s. This training method results in a tension-time index of 0.3 (PImax 0.7, T/Ttot 0.43). Bellamare and Grassino showed that a tension-time index of 0.3 resulted in fatigue of the diaphragm in about 10 to 15 minutes.
minutes. Therefore, on theoretic grounds, we believed that this was a reasonable training intensity. Practically, the training sessions were fairly well tolerated by the patients.

The endurance of the diaphragm was improved in the PR as well as in the PR + IMT group, although significantly more in the latter group. It seems, therefore, that exercise as such may result in a training stimulus for the diaphragm, presumably by increasing minute ventilation during the training sessions.

In conclusion, adding TF-IMT to a PR program is useful in patients with COPD with ventilatory limitation, and it results in significantly more improvement in inspiratory muscle strength and diaphragm endurance as well as general exercise endurance than PR alone.

ACKNOWLEDGMENTS: The authors gratefully acknowledge the financial support by the Dutch Asthma Foundation (grant No. 86.31).

REFERENCES