ABSTRACT. The purpose of this study was to measure the effects on mucus clearance after physical exercise. We measured mucociliary clearance at rest and during exercise in eleven patients with mild or moderate bronchial hypersecretion. The subjects inhaled an aerosol containing $^{99m}$Tc-labelled albumin micromolecules. Four sets of scintigraphic images were obtained with 15 minute intervals. The lung retention of radioactivity was quantified using a gamma camera and the clearance of particles from the lungs was calculated for each 15 minute period. The first image was obtained directly after initiation, the second after a period of 15 min rest, the third after a period of exercise on a bicycle ergometer and the final fourth image after another period of rest. We found no differences in the clearance rate at rest and after exercise.

Keywords: aerosol, radionuclide imaging, respiratory function test, bronchial hypersecretion, chronic bronchitis.

Mucus is cleared from the airways by mucociliary transport and by cough. The rate of transport of inhaled particles deposited on ciliated airways can be measured by external monitoring of the clearance of inhaled radionuclide particles (16).

Mucociliary clearance is affected by autonomic stimuli. Adrenergic (8, 12, 14) as well as cholinergic drugs (7) increase the rate of clearance. Mucociliary clearance is slower during sleep than in wakefulness. In view of this, mucociliary clearance might be expected to increase during exercise. The effects of physical activity on clearance has been studied in normal subjects with conflicting results. Wolff et al. (21) found clearance to be slightly increased after exercise, whereas no substantial effect was seen in a study by Östlin & Wolfmer (19).

Patients with bronchial hypersecretion often have reduced mucociliary clearance, and various forms of chest physiotherapy are used to increase the elimination of secretions. Traditional chest physiotherapy includes breathing exercises, cough, postural drainage, percussion and vibration. The basic mechanism

for and efficacy of each component are incompletely known, and the optimal scheme for chest physiotherapy remains controversial (13, 20).

In recent years, increasing emphasis has been placed on techniques for physical therapy which include physical activity and active participation of the patient. Various forms of exercise have thus been introduced in the physical therapy of patients with chronic lung disease and been shown to improve exercise tolerance and gas exchange (3, 9, 10, 15). Physical exercise has therefore been suggested to improve the quality of life in patients with chronic lung diseases.

Little is known about the effect of exercise on mucus clearance in patients with bronchial hypersecretion. We are aware of only one study in which mucus clearance was found to be greater during exercise than at rest (18).

The purpose of this study was to measure the effects on mucus clearance of a simple exercise program which could be done by the patient on his own.

MATERIAL AND METHODS

We studied mucociliary clearance at rest and during exercise in eleven patients (6 men and 5 women) with bronchial hypersecretion. Their daily sputum production was estimated from the history to be about 20-30 ml. Eight patients, four current smokers and four ex-smokers, had chronic bronchitis and three non-smoking patients had bronchiectasis. Their mean age was 51 ± 12 (SD) years. The study was approved by the local research ethics committee and informed consent was obtained from each subject.

Spirometry including vital capacity (VC) and forced expiratory volume in one second (FEV1) was performed with a bellows spirometer. Predicted values were obtained from Berghold et al. (5).

Mucus clearance was assessed with a technique based on measurement of the clearance of inhaled radioactive particles. The subject was positioned in front of a gamma camera (Mitsubishi 40T, General Electric Company, Milwaukee, Wk., USA). A transmission scintigram of the chest was obtained using a fanned source Fig. 1. A large disc containing $^{68}$Ga was placed over the anterior aspect of the chest and the gamma rays transmitted through the thorax detected with the

Table 1. Heart rate and ventilatory parameters at rest and during exercise

<table>
<thead>
<tr>
<th></th>
<th>Heart rate (min⁻¹)</th>
<th>Breathing frequency (min⁻¹)</th>
<th>Ventilation (l/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest</td>
<td>88 ± 15</td>
<td>18 ± 4</td>
<td>17 ± 4</td>
</tr>
<tr>
<td>Exercise</td>
<td>124 ± 17</td>
<td>23 ± 6</td>
<td>40 ± 10</td>
</tr>
</tbody>
</table>

RESULTS

Vital capacity and FEV₁ were slightly to moderately reduced in most patients, mean values being 86 ± 23 and 82 ± 25 % of the predicted values, respectively. The scintigrams obtained immediately after the inhalation of aerosol showed prominent deposition of particles in the central airways. On average, 46% of the aerosol was deposited in the central region and 54% in the peripheral region.

The heart rate during exercise corresponded to 74% of the predicted maximum heart rate (Table I). Minute ventilation increased by a factor 2.4.

All patients but one coughed during the exercise measurement. The number of coughs were from 0 to 27 with a mean of 2.6. There was no significant difference in the number of coughs between the different periods of measurement.

Clearance of radioactive particles from the whole lung field was greater during the first period of rest than during exercise and greater during the second period of rest (Table II), but the differences were not statistically significant. The findings in the peripheral region were similar to those in the whole lung field. Clearance from the central region during exercise was slightly faster during exercise than during the periods of rest, but again the differences were not statistically significant.

DISCUSSION

The technique we used for assessing mucous clearance relies on measurement of the clearance of inhaled radioactive labelled particles. We measured clearance during different periods after a single inhalation of tritiated water, which is probably related to particle deposition on non-iliated epithelium. The effect of such deposition would be expected to be less in the central region than in the peripheral region since most of the radioactivity measured in the central region originates from large airways. In the central region in contrast, clearance was slightly better, but not significantly higher during exercise than at rest.

We thus found no evidence that moderate exercise increases mucous clearance in patients with bronchial hypersecretion. With the experimental design used in this study, small effects of exercise on mucous clearance may have been overlooked. We feel confident, however, that any clinically relevant beneficial effect of exercise on mucous clearance would be detectable.

Oldenburg et al. (18) measured mucous clearance in subjects with chronic bronchitis during intermittent exercise (5×4 min with 4 min intervals). They found clearance to be slightly better, but significantly faster during exercise than at rest. They also found, however, that directed coughing alone improved mucous clearance much more than exercise. The patient material in the study by Oldenburg et al. differs from our material by having greater spurt production and greater lung function impairment. A possible explanation for the differences between our results and the results of Oldenburg and co-workers could be that exercise has a greater effect on mucociliary clearance when the patients produce more secretion.

ACKNOWLEDGEMENTS

This study was supported by grants from the Swedish Medical Research Council (no. 02872), the Swedish National Association against Chest and Heart Diseases and All Procedura Nova.

REFERENCES


The patient inhaled the aerosol with somewhat forced breaths so that a high deposition should be obtained on ciliated epithelium. Heavy deposition in central airways was also seen in all subjects. Nevertheless, some deposition can be expected to occur in peripheral airways, possibly beyond the ciliated epithelium. This aerosol would constitute a background activity in the clearance measurement. Allowance for the deposition on non-ciliated epithelium can be made by measuring the 24 h retention of particles or by relating the deposition of particles to regional ventilation (16). Neither approach could, for practical reasons, be used in this study. Instead, we related mucociliary clearance during exercise to two periods of rest, one preceding and the other following exercise.

The use of exercise, as a means of self-administered physical therapy in patients with chronic lung disease, is limited to exercise at moderate work load for a relatively short time. We therefore chose to study the subjects at the sub-maximal work load for approximately 15 min.

Cough is considered an important mechanism for mucous clearance in patients with bronchial hypersecretion (2, 6). In this study, we made no attempt to eliminate the effect of cough, since this was felt to create too artificial a situation. Instead, we counted the number of coughs during each period of measurement.

We did not find any statistically significant difference in mucous clearance between the periods. Clearance gradually slowed down during the periods in the whole lung field and in the peripheral field. This suggests that the clearance rate decreases with time, which is probably related to particle deposition on non-ciliated epithelium. The effect of such deposition would be expected to be less in the central region than in the peripheral region since most of the radioactivity measured in the central region originates from large airways. In the central region in contrast, clearance was slightly better, but not significantly higher during exercise than at rest.

We thus found no evidence that moderate exercise increases mucous clearance in patients with bronchial hypersecretion. With the experimental design used in this study, small effects of exercise on mucous clearance may have been overlooked. We feel confident, however, that any clinically relevant beneficial effect of exercise on mucous clearance would be detectable.
RESULTS
Vital capacity and FEV1 were slightly to moderately reduced in most patients, mean values being 86±23 and 88±2.25% of the predicted values, respectively. The scintigrams obtained immediately after the inhalation of aerosol showed prominent deposition of particles in the central airways. On average, 46% of the aerosol was deposited in the central region and 54% in the peripheral region.

The heart rate during exercise corresponded to 74% of the predicted maximum heart rate (Table I). Minimal ventilation increased by a factor 2.4. All patients but one coughed during exercise.

Clearance of radioactive particles from the whole lung field was greater during the first period of rest than during exercise and greater during the second period of rest (Table II), but the differences were not statistically significant. The findings in the peripheral region were similar to those in the whole lung field.

In the patients with chronic bronchitis, the number of coughs during each period of measurement.

DISCUSSION
The technique we used for assessing mucociliary clearance relies on measurement of the clearance of inhaled radioactive particles. We measured clearance during different periods after a single inhalation of tracer rather than on different occasions. This design was selected because of the well-known difficulty to achieve reproducible aerosol deposition (11).

Table II. Clearance of radioactive particles from the lung regions at rest and during exercise expressed as the amount cleared during each period of measurement relative to the initial activity at the beginning of each period

<table>
<thead>
<tr>
<th>Clearance (%) initial activity</th>
<th>Total</th>
<th>Central</th>
<th>Peripheral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest 1</td>
<td>11.2±5.1</td>
<td>25.1±14.3</td>
<td>10.7±4.6</td>
</tr>
<tr>
<td>Exercise</td>
<td>10.6±2.7</td>
<td>31.9±16.7</td>
<td>9.7±4</td>
</tr>
<tr>
<td>Rest 2</td>
<td>7.1±3.1</td>
<td>29.8±19.5</td>
<td>8.0±3.4</td>
</tr>
</tbody>
</table>

The patient inhaled the aerosol with somewhat forced breath so that a high deposition should be obtained on ciliated epithelium. Heavy deposition in central airways was also seen in all subjects. Nevertheless, some deposition can be expected to occur in peripheral airways, possibly beyond the ciliated epithelium. This aerosol would constitute a background activity in the clearance measurement. Allowance for the deposition on non-ciliated epithelium can be made by measuring the 24 h retention of particles or by relating the deposition of particles to regional ventilation (16). Neither approach could, for practical reasons, be used in this study. Instead, we related mucociliary clearance during exercise to two periods of rest, one preceding and the other following exercise.

The use of exercise, as a means of self-administered physical therapy in patients with chronic lung disease, is limited to exercise at moderate work load for a relatively short time. We therefore chose to study the subjects at sub-maximal work load for approximately 15 min.

Cough is considered an important mechanism for mucous clearance in patients with bronchial hypersecretion (2, 6). In this study, we made no attempt to eliminate the effect of cough, since this was felt to create too artificial a situation. Instead, we counted the number of coughs during each period of measurement.

We did not find any statistically significant difference in mucous clearance between the periods. Clearance gradually slowed down during the periods in the whole lung field and in the peripheral field. This suggests that the clearance rate decreases with time, which is probably related to particle deposition on non-ciliated epithelium. The effect of such deposition would be expected to be less in the central region than in the peripheral region, since most of the radioactivity measured in the central region originates from large airways. In the central region in contrast, clearance was slightly but not significantly higher during exercise than at rest.

We found no evidence that moderate exercise increases mucous clearance in patients with bronchial hypersecretion. With the experimental design used in this study, small effects of exercise on mucous clearance may have been overlooked. We feel confident, however, that any clinically relevant beneficial effect of exercise on mucous clearance would be detectable.

Oldenburg et al. (18) measured mucous clearance in subjects with chronic bronchitis during intermittent exercise (5×4 min with 4 min intervals). They found clearance to be slightly, but significantly faster during exercise than at rest. They also found, however, that directed coughing alone improved mucous clearance much more than exercise. The patient material in the study by Oldenburg et al. differs from our material by having greater sputum production and greater lung function impairment. A possible explanation for the differences between our results and the results of Oldenburg and co-workers could be that exercise has a greater effect on mucociliary clearance when the patients produce more sputum.

ACKNOWLEDGEMENTS
This study was supported by grants from the Swedish Medical Research Council (no. 02572), the Swedish National Association against Chest and Heart Diseases and All Procedera Nova.

REFERENCES
<table>
<thead>
<tr>
<th>Date</th>
<th>Place</th>
<th>Name</th>
<th>Office</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 1992</td>
<td>Toronto</td>
<td>Annual Meeting of the American Spinal Injury Association</td>
<td>Inf. American Spinal Injury Assoc., 2020 Peachtree Rd, NW, Atlanta, GA 30309, USA</td>
</tr>
<tr>
<td>May 1992</td>
<td>Tel Aviv</td>
<td>Intern. Symp. on the Rehabilitation of the Patient with Brain Damage - The young and the old</td>
<td>Inf. Public Sotz, MD, c/o Intern. Ltd, Box 29313, 61292 Tel Aviv, Israel</td>
</tr>
<tr>
<td>June 1992</td>
<td>Harrogate</td>
<td>IVth Intern. Symp. for Health Professionals in Rheumatology</td>
<td>Inf. Dr H. A. Bird, Royal Bath Hosp., Cornewall Rd, Harrogate N. Yorkshire, HG1 2PS, GB</td>
</tr>
<tr>
<td>June 1992</td>
<td>Munich</td>
<td>Second Intern. Congress of Movement Disorders</td>
<td>Inf. Secretariat ISMD, Box CH-4005, Basel, Switzerland</td>
</tr>
<tr>
<td>June 1992</td>
<td>The Netherlands</td>
<td>Summer University Health Sciences and Medicine</td>
<td>Inf. The Univ. of Limburg, Faculty of Health Sciences Medicine, Box 616, 6200 MD Maastricht, The Netherlands</td>
</tr>
<tr>
<td>June 1992</td>
<td>Toronto</td>
<td>RESNA '92 Conference on Technology: Gateway to Rehabilitation</td>
<td>Inf. RESNA, Suite 700, 1101 Connecticut Ave, N.W. Washington, DC 20036</td>
</tr>
<tr>
<td>June 1992</td>
<td>Chigaco, IL</td>
<td>Seventh World Congress of the Intern. Society for Prosthetics and Orthotics on 'Find the New World Developing Around the Globe'</td>
<td>Inf. Munroeves, Inc., 400 North Michigan Ave, Suite 2300 Chicago, Ill. 60611</td>
</tr>
<tr>
<td>July 1992</td>
<td>Bordeaux</td>
<td>5th World Congress of Cardiac Rehabilitation</td>
<td>Inf. Dr. J. P. Broussart, Hosp. Cardiologique du Haut Lévêque Ave de Magellan, 33004 Pessac</td>
</tr>
<tr>
<td>Aug. 1992</td>
<td>Venice</td>
<td>11th Biennial Congress of the Int. Assoc. of Dentistry for the Handicapped</td>
<td>Inf. Endar Centro Congressi Castillo 4966, 301 22 Venice, Italy</td>
</tr>
<tr>
<td>Aug. 1992</td>
<td>Copenhagen</td>
<td>2nd World Congress on Myofacial Pain and Fibromyalgia</td>
<td>Inf. Danish Rheumatism Assoc. Giglforgreven, Hauchwolche 14, DK-1825 Foderiksberg, Denmark</td>
</tr>
<tr>
<td>Sept. 1992</td>
<td>Budapest</td>
<td>The 6th European Regional Conf. of Rehabilitation International</td>
<td>Inf. Secretariat ISM Ltd, The Old Vicarage, Hatly Hill, Halflax HX3 6DR, GB</td>
</tr>
<tr>
<td>Sept. 1992</td>
<td>Saumarkki</td>
<td>Fifth Intern. Conf. on the Combined Effects of Environmental Factors</td>
<td>Inf. Oulu Regional Inst. of Occup. Health, Box 431, SF-90101 Oulu</td>
</tr>
</tbody>
</table>

Address for addresses: Lone Olvesti
Department of Long Medicine
Lasseetan S-220 85 Lund, Sweden