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Efficacy of Coughing in Tetraplegic Patients

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Study Design. A randomized cross-over design study in six tetraplegic patients.

Objectives. To investigate the efficacy of coughing in tetraplegic patients.

Summary of Background Data. In tetraplegic patients, pulmonary complications due to insufficient clearance of bronchial mucus frequently are described. Coughing in tetraplegic patients is thought to be insufficient because of severely impaired expiratory muscle function. More recently, however, it has been reported that many tetraplegic patients may have dynamic airway compression and thus a more or less effective cough.

Methods. Mucus clearance was measured using a radioactive aerosol tracer technique during 45 minutes on 2 days: once without intervention, and once with voluntary coughing in the period 15 to 30 minutes (once every 30 seconds). Measurements were done in a randomized order. For each day, individual slopes for the decrease in radioactivity were calculated, reflecting mucus transport in the peripheral, central, and the whole lung region.

Results. Significant differences in slopes were found between the control day and the cough day in the peripheral lung region for the interval 0 to 30 minutes and in the whole lung region for the interval 0 to 30 minutes and 0 to 45 minutes. The improvement of mucus clearance due to coughing, however, was relatively small in these patients, only 3% after 45 minutes: from 4% whole lung clearance during quiet breathing to 7% whole lung clearance during coughing.

Conclusion. Tetraplegic patients may achieve a statistically significant increase in their bronchial mucus transport by voluntary coughing. [Key words: cough, efficacy, tetraplegia] **Spine 2000;25:2200–2203**

In longstanding tetraplegic patients, pulmonary complications frequently are described. For instance, Minaire et al[4] followed up 848 patients with a spinal cord injury. In this study, 48 deaths were recorded, of which 20 were attributed to pulmonary complications. Pulmonary complications in these patients are the result of the impaired expiratory muscle function. Expiratory muscle impairment reduces the ability to cough and thus to clear the airways from excessive bronchial secretions. A stasis of bronchial secretions may predispose to the development of pulmonary infections. Sufficient clearance of bronchial secretions may prevent pulmonary complications and thus contribute to a better survival of patients with a spinal cord injury.[7] The most important technique for bronchial clearance is the generation a high expiratory flow velocity in the airways.[11] High airflow velocities can be achieved by high expiratory flow and the development of dynamic compression of the airways. Dynamic compression is the result of differences in intrabronchial and extrabronchial pressure. During a forced expiration, the intrabronchial pressure decreases from the peripheral airways to the mouth because of frictional pressure loss and convective acceleration pressure loss. Somewhere in this pressure decay there is a point where the intrabronchial pressure equals the extrabronchial pressure. This point is called the equal pressure point (EPP). Upstream, in the direction of the alveoli, the intrabronchial pressure is greater than the extrabronchial pressure, and no compression takes place. Downstream, in the direction of the mouth, the extrabronchial pressure is greater than the intrabronchial pressure, and compression of the airways can take place depending on the stiffness of the airway wall.

In an experimental model study, it was found that airway narrowing greatly enhances cough-induced mucus transport.[10] Dynamic compression of the airways is considered an essential part of effective cough-induced mucus clearance.

For a long time it has been assumed that tetraplegic patients could not have an effective cough because of severely impaired expiratory muscle function. More recently it has been reported that a considerable number of longstanding tetraplegic patients may have developed expiratory techniques resulting in dynamic airway compression and thus a more or less effective cough. Estenne and colleagues found circumstantial evidence for dynamic airway compression during forced expiratory maneuvers in tetraplegic patients.[2,3] These authors suggested that at least some longstanding tetraplegic patients may have developed an effective cough. A potential explanation by these authors is that the clavicular part of the pectoralis major muscle acts as an expiratory muscle. This implies that cough in these patients is an active rather than a passive process. Until now, however, no data have been available concerning the effect of coughing on bronchial mucus transport in tetraplegic patients. The purpose of this study was to investigate cough effectiveness on mucus clearance in longstanding tetraplegic patients.

Patients and Methods

Patients. Six tetraplegic patients were recruited by their willingness to take part in this study. All patients gave written informed consent. The characteristics of the patients are given in Tables 1 and 2. The study was approved by the Medical Ethics Committee.

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Table 1. Characteristics of the Patients

	Mean (SD)
Age	40 (10)
Gender (M/F)	6/0
PEF, L/sec	6.75 (1.35)
FEV_1, L	3.41 (0.62)
FVC, L	3.79 (0.58)
FEV_1/FVC	0.89 (0.07)
pMIP, cm H_2O	88 (37)
MIP, cm H_2O	81 (32)
pMEP, cm H_2O	71 (19)
MEP, cm H_2O	66 (21)

PEF = Peak expiratory flow; FEV_1 = Forced expiratory volume in the first second after a maximal inspiration; FVC = Forced vital capacity; FEV_1/FVC = Ratio between FEV_1 and FVC; MIP = Maximal inspiratory pressure that could be sustained for at least 1 second; pMIP = Peak maximal inspiratory pressure; MEP = Maximal expiratory pressure that could be sustained for at least 1 second; pMEP = Peak maximal expiratory pressure.

Pulmonary Function. Pulmonary function was measured using an electronic hand-held spirometer (SensorMedics). The patient was asked to take a maximal deep inspiration and then a maximal forced expiration. The following variables were measured: Peak Expiratory Flow (PEF), Forced Expiratory Volume in the first second after starting the forced expiration (FEV_1) and Forced Vital Capacity (FVC). Additionally, the maximal inspiratory and the maximal expiratory mouth pressures were measured. These pressures are considered to reflect the force to the inspiratory and expiratory muscles. The inspiratory pressure was measured from residual volume, and the expiratory pressure was measured from total lung capacity. The peak value and the values that could be sustained for at least 1 second were taken for analysis for both pressures. No instruction was given about the performance techniques of the tests. The patients were allowed to use compensatory movements of the upper extremity and trunk to achieve the highest possible pressures.

Mucus Clearance Measurements. Clearance of bronchial secretions was measured by timing the transport rate of a tracer deposited on the bronchial mucus layer.[8,9] A radioactive aerosol was produced using a triggered intermittent positive pressure jet nebulizer. The nebulizer was filled with 1 mL ^{99m}Tc-tin colloid (Amersham) in a dosage between 35–50 MBq and 4 mL NaCl. The patients used a nose-clip and inhaled the aerosol by mouth during 30 tidal breathing inspirations. In this way, 10 to 15% of the tracer is deposited in the lower airways. After that, the patients were asked to wash their mouth and to swallow some water to clear the mouth, throat, and esophagus from

Table 2. Individual Characteristics of the Patients in This Study

Patient	Age (yr)	Time Since the Lesion	Level of the Lesion	ASIA[1,6]
1	42	19 yrs	Th1-complete	16
2	28	11 yrs	C5/C6 complete	23
3	44	9 mos	C7/C8 incomplete	29
4	50	7 mos	C5 incomplete	74
5	51	14 mos	C6 complete	37
6	30	3 yrs	C6/C7 complete	21

ASIA = American Spinal Injury Association.

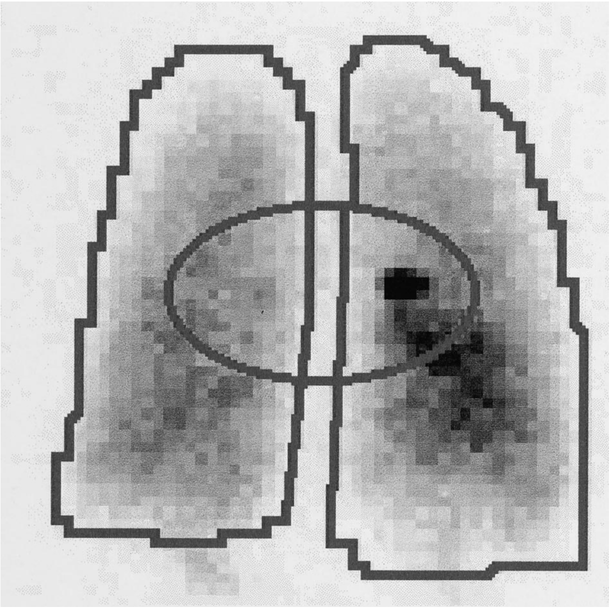

Figure 1. An example of the deposition pattern in the hilar and peripheral regions.

radioactive tracer. The radiation dose using this method is 0.6 mGy, and the total body radiation dose was 0.1 mGy.[5] Radioactivity deposited on the airway surface after inhalation of the aerosol was recorded with a gamma camera in 1-minute frames during 45 minutes. The contours of the lungs were drawn visually on the monitor using a joystick. An oval region of interest was determined visually on the monitor over both hili by positioning the midpoint of this region between the lungs and by varying the x-axis and y-axis. The same position was used during the second test. The peripheral region was defined by subtracting the central region from the whole lung region (see Figure 1).

The number of counts for each region was corrected for physical decay and expressed as a percentage of the starting value. From these data, individual retention curves were generated for each region. The decrease of the amount of radioactivity is considered to reflect transport of mucus in the airways. For each individual curve, the slope was calculated using linear regression analysis. These individual slopes were taken for analysis.

Mucus clearance measurements were done on 2 days, always at the same time of the day. At random, a period of voluntary coughing was included in one of these days between 15 to 30 minutes after starting the mucus clearance measurements. In this period, the subjects were asked to cough as effectively as possible once every 30 seconds.

Statistical Analysis. The individual slopes of the control measurement and the measurement that included the 15-minute coughing period were compared using Wilcoxon Signed Ranks Test. A P value of 0.05 and lower was considered statistically significant.

■ Results

The mean slopes during the control day and the cough day for the intervals 0 to 15 minutes, 0 to 30 minutes,

Table 3. Mean (SD) Slopes During the Control Day and the "Cough" Day for the Different Regions and Time Intervals

Region	Control Day	Cough Day	*P* Value*
Hilar 0–15 min	−0.084 (0.439)	−0.237 (0.353)	0.565
Hilar 0–30 min	−0.079 (0.131)	−0.272 (0.213)	0.167
Hilar 0–45 min	−0.072 (0.134)	−0.212 (0.165)	0.097
Peripheral 0–15 min	−0.024 (0.170)	−0.064 (0.232)	0.658
Peripheral 0–30 min	−0.094 (0.117)	−0.189 (0.080)	**0.020**
Peripheral 0–45 min	−0.089 (0.061)	−0.142 (0.069)	0.126
Whole lung 0–15 min	−0.049 (0.133)	−0.106 (0.235)	0.675
Whole lung 0–30 min	−0.091 (0.115)	−0.0212 (0.068)	**0.032**
Whole lung 0–45 min	−0.082 (0.071)	−0.160 (0.078)	**0.033**

* *P* values of the paired Student's *t* test.

and 0 to 45 minutes are given in Table 3 and Figures 2 to 4. Significant differences were found between the control day and the cough day in the peripheral region for the interval 0 to 30 minutes and in the whole lung region for the interval 0 to 30 minutes and 0 to 45 minutes.

Discussion

The results of this study show that tetraplegic patients can reach a statistically significant increase in bronchial mucus clearance during coughing.

A statistically significant increase in mucus clearance, reflected by the slope of the individual regression coefficients, was found during the measurement with coughing as compared with control measurement in the whole lung region but not in the peripheral lung region nor in the hilar lung region. This finding supports the suggestion of Estenne et al[2,3] that tetraplegic patients may have an effective cough. The absence of an effect of cough on the hilar region may occur because, in the hilar region,

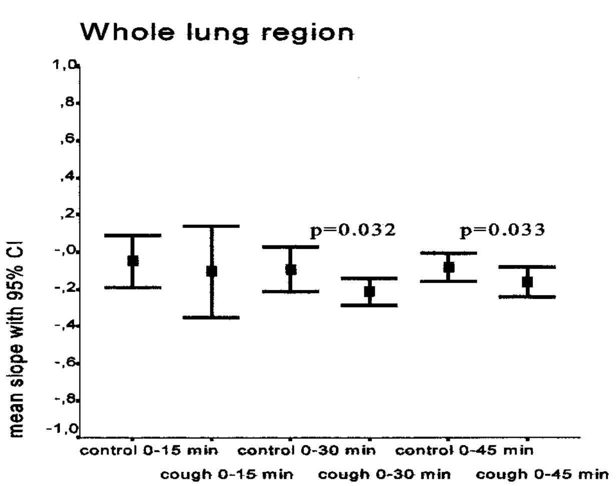

Figure 2. Slopes of the decrease in the amount of radioactivity in the whole lung region.

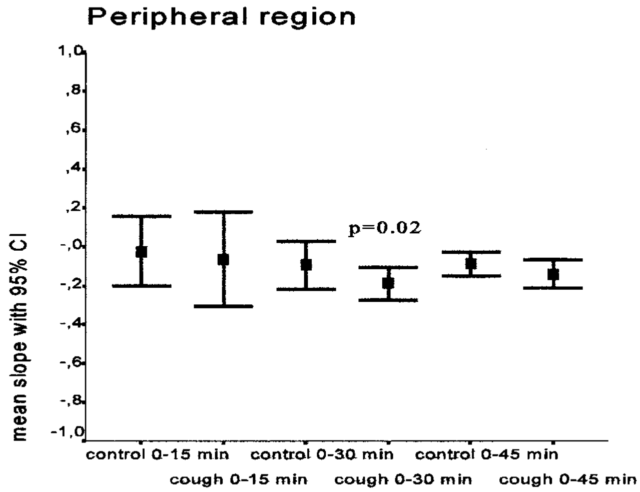

Figure 3. Slopes of the decrease in the amount of radioactivity in the peripheral lung region.

there is clearance of mucus from the hilar region to the esophagus, but also supply of mucus from the peripheral region. Cough-induced clearance of mucus from the peripheral regions is usually less than from more central regions. This is because the airflow velocity is lower in the peripheral than in the central airways.

Coughing or forced expirations with an open glottis are the most important clearance mechanisms for bronchial mucus. In patients with pulmonary diseases like cystic fibrosis or chronic obstructive pulmonary disease (COPD), these measures are very effective. Until now, little was known about the clinical relevance of improvement in bronchial mucus clearance. It was thought that improvement of mucus clearance may have beneficial effects on the progress of the pulmonary disease and on the development of exacerbations or pulmonary infections. Little is known about which improvement of mucus clearance is relevant, however, and which is not. The improvement of mucus clearance in the patients in this

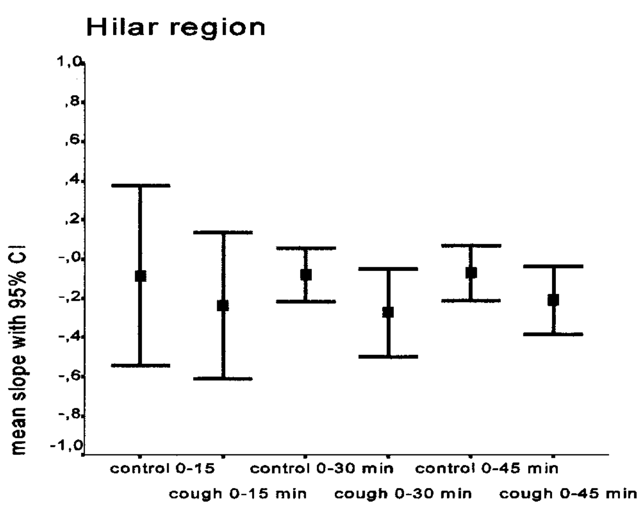

Figure 4. Slopes of the decrease in the amount of radioactivity in the hilar lung region.

study was approximately 3%: from 4% during quiet breathing to 7% during coughing. This improvement was less than has been described in patients with pulmonary disease. In an earlier study in patients with COPD, an improvement of peripheral lung region clearance from approximately 5 to 20% was found.[8] Despite the statistical significance, the clinical significance of coughing in these patients is not clear.

From earlier studies, it is clear that the effectiveness of coughing in transporting mucus is also dependent of the thickness of the mucus layer. An increased thickness of the mucus layer improves the transportability of mucus by airflow. The patients in the present study had no signs of severe retention of mucus. In case of severe retention of mucus, and thus an increased thickness of the mucus layer, the effect of coughing may be greater as compared with a situation without severe mucus retention.

■ Conclusion

Tetraplegic patients may reach a statistically significant increase in their bronchial mucus transport. This effect is small, however, and may not be clinically significant. Additional measures, besides coughing, are needed to prevent and treat mucus retention in tetraplegic patients.

■ Key Points

- In a randomized cross-over study, the effect of coughing on bronchial mucus transport was measured in tetraplegic patients.
- A small but statistically significant increase in mucus transport during coughing was found compared with the control period.

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