International Journal of Occupational Medicine and Environmental Health, Vol. 15, No. 3, 279—287, 2002

LUNG FUNCTION AND SURFACE ELECTROMYOGRAPHY OF INTERCOSTAL MUSCLES IN CEMENT MILL WORKERS

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Abstract. Impairment of pulmonary function in cement mill workers has been previously reported without considering a variety of parameters that can help evaluate more thoroughly the effect of cement dust on the respiratory system. In addition, an integrated approach has not been considered to assert the involvement of respiratory muscles. Therefore, in the present study spirometry and surface electromyography (SEMG) of intercostal muscles were used for indicating pulmonary impairment. In this study, a group of 50, apparently healthy volunteers, male cement mill workers aged 20–60 years with exposure of 13 years on average, were randomly selected. They were matched with another group of 50 control healthy male subjects in terms of age, height, weight and socioeconomic status. Both groups met the standard exclusion criteria. Spirometry was performed on an electronic spirometer, while SEMG of intercostal muscles was performed by using a chart recorder. The results demonstrated statistically significant reduction in lung function parameters i.e., force vital capacity (FVC) ($p < 0.0005$); force expiratory volume in first second (FEV_1) ($p < 0.0005$); peak expiratory flow (PEF) ($p < 0.005$); and maximum voluntary ventilation (MVV) ($p< 0.0005$) in cement mill workers, when compared with controls. However, the FEV_1/FVC ratio was significantly higher ($p < 0.025$) in cement mill workers. Similarly, the parameters obtained from SEMG of intercostal muscles, i.e. number of peaks (NOP) ($p < 0.0005$); maximum peak amplitude (MPA) ($p < 0.0005$); peak to peak amplitude (PPA) ($p < 0.0005$); duration of response (DOR) ($p < 0.0005$) and maximum peak duration (MPD) ($p < 0.0005$), were significantly lower in cement mill workers than in controls.
It is concluded that exposure to cement dust not only impairs lung function but also affects costal muscle performance, thus possibly indicating the decreased lung and thoracic compliance.

Key words:
Lung function, Surface electromyography, Cement dust, Occupational hazards

INTRODUCTION

Portland cement is a gray powder-like adhesive substance and is a mixture of calcium oxide, silicon oxide, aluminum tri oxide, ferric oxide, magnesium oxide [1] selenium [2] thallium and also other impurities [3]. Cement production involves dust generation especially when grinding the clinker, blending, packing and transport of the finished products [4]. The aerodynamic diameter of cement particles range from 0.05 to 5.0 μm. This size is within the size of respirable particles and make the tracheobronchial respiratory zone the primary target of cement deposition, hence cement dust is important as a potential cause of occupational pulmonary disease [5]. The deposition of inhaled particles are influenced by the physical and chem-

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ical properties of the inhaled agent and also by various host factors [6]. Problems may arise with this sort of dust exposure, when one or more protective mechanisms are damaged. If dusty air is breathed continuously and heavily mixing between the inspired and the dead space, the air will cause some dust to reach the terminal airways. The dust tends to accumulate in the alveoli, in the periphery of the lobule [7] and with the passing time causes inflammatory changes and ultimately fibrosis.

Long-term exposure to cement dust, can develop clinical symptoms like cough, phlegm production, chest tightness, skin irritation, conjunctivitis, stomach ache and boils [1]. These may be due to inflammatory responses, leading to structural and functional abnormalities [8] primarily in the lungs. Cement dust also causes cancer of the colon [9]. Spirometry is a widely used basic pulmonary function test. It is used to determine the extent of impairment and to assess the response to treatment [10]. Similarly, electromyography (EMG) is a useful method for the detection, registration and quantification of various disturbances of function in the nerve and muscle. Hence, this technique is helpful in detecting disorders of motor units and in determining the nature and the site of underlying lesion [11]. In spite of advances in genetics, molecular biology, chemistry and histochemistry, EMG still plays a central role in the evaluation of patients with neuromuscular disorders [12,13] and is also helpful in early detection of occupational hazards [14]. In addition, surface electromyography (SEMG) has found several applications, mainly when the summated activity in a muscle or a muscle group should be studied [15]. Reliability of SEMG has been well documented because of its non-invasive nature [16]. It has been described that the assessment of respiratory muscle function by using EMG is more closely related to the activities of the respiratory center [17]. SEMG of respiratory muscle is one of the most reliable methods of assessing the ventilatory muscle functions. The strength of ventilatory muscle is affected by numerous factors, including lung volume, prematurity, atrophy, neuromuscular disorders and nutritional state [18]. Paralysis of intercostal muscle causes rigidity in the chest wall, as well as reduces the movement of the ribs [19] and mechanical properties of the lungs and the chest wall [20]. SEMG has also been used to investigate the relationship between airway obstruction and the activity of the diaphragm and intercostal muscles [21].

MATERIALS AND METHODS

This study was conducted in the Department of Physiology, Faculty of Health and Medical Sciences, Hamdard University Karachi and University of Karachi, Karachi, Pakistan. In this study two groups were formed with 50 volunteers each. In the first group, 50 volunteers apparently healthy male cement mill workers, aged 20–60 years and exposed for 12.94 ± 1.00 years (mean ± SE), were selected randomly among employees of the cement mill located in Karachi, Pakistan. They were matched for age, height, weight and socioeconomic status with another group of 50 healthy male control subjects selected from the local population of Karachi. All subjects completed a questionnaire, which included anthropometric data and a consent form. The Ethics Committee of the Hamdard University approved the study protocol.

Exclusion criteria

Subjects with gross abnormalities of the vertebral column, thoracic cage, neuromuscular diseases, known cases of gross anemia, asthma, diabetes mellitus, cardiopulmonary diseases, malignancy, drug addicts, cigarette smokers and subjects who had undergone vigorous exercise, abdominal or chest surgery were excluded from the study.

Spirometry

Spirometry was performed on an electronic spirometer (Compact Vitalograph UK). All the pulmonary function tests were carried out at a fixed time of the day (9:00–13:00) to minimize the diurnal variation [22]. The apparatus was calibrated daily and operated within the temperature range of 20–25°C. The precise technique of performing various lung function tests for the present study was based on the operation manual of the instrument with special reference to the official statement of the American Thoracic Society of Standardization of Spirometry (1987) [23]. After taking a detailed history and collecting anthropometric data, the subjects were informed about the whole manoeuvre. The subjects were encouraged to practice this manoeuvre before doing the pulmonary test. The test was performed with the subject in the standing position by using a nose clip. The test was repeated three times after adequate rest; after completing the test, the spirometer selected the highest value and printed the results with built-in printer. The following lung function parameters were considered: force vital capacity (FVC), force expiratory volume in first second (FEV_1), force expiratory ratio (FEV_1/FVC), peak expiratory flow (PEF), force expiratory flow ($FEF_{25-75\%}$) and maximum voluntary ventilation (MVV).

Surface electromyography

SEMG was performed by using Lafayette instrument (Model 76107, TMGIC, S/N 312993, USA) at a fixed time of the day (9:00–13:00). For recording the electromyogram the experimental setup included chart recorder, isolated preamplifier (Lafayette), lead electrodes, disposable surface electrodes, gel and skin cleansing material (razor and spirit-swab). After cleansing and counting the intercostal space, surface electrodes were applied on the 7th and 8th right side of intercostal spaces. Before starting the recording, speed and gain of chart recorder was adjusted to get appropriate record. In order to obtain the SEMG records, subjects were asked to deeply inspire and then deeply expire, avoiding unnecessary body movements. For each subject this action was repeated to have 5 observations recorded at a chart speed of 25 ms. At the end of the experiment, an internal calibration signal of 1 mV was obtained through isolated preamplifier for the quantification of the EMG signal for an analysis. The following parameters were measured from the SEMG records: number of peaks (NOP), maximum peak amplitude (MPA), peak to peak amplitude (PPA), duration of response (DOR) and maximum peak duration (MPD).

The obtained data for various spiromteric and SEMG parameters were statistically analyzed. The statistical comparison was made among cement mill workers and controls by applying the paired t-test. The level of probability taken as significance was $p < 0.05$.

RESULTS

Anthropometric studies

Anthropometric parameters for the total number of cement mill workers and the control group are shown in Table 1. There were no significant differences between the means of anthropometric parameters, i.e. age, height or weight in both groups.

Table 1. The comparison of anthropometric parameters between cement mill workers and controls (n = 50)

Parameters	Control subjects (mean ± SE)	Cement mill workers (mean ± SE)	Significance level
Age (yr)	37.80 ± 1.66	36.86 ± 1.50	NS
Height (cm)	165.24 ± 0.89	165.64 ± 0.85	NS
Weight (kg)	63.72 ± 1.10	6.70 ± 1.39	NS

NS – Non significant. SE – Standard error.

Pulmonary function test

The mean values of lung function parameters for the total number of cement mill workers and controls are presented in Table 2. In cement mill workers, a statistically significant reduction was demonstrated in the mean values of FVC, FEV_1, PEF, and MVV. The mean value for FEV_1/FVC ratio was significantly higher in cement mill workers. While the mean value of $FEF_{25-75\%}$ showed no significant difference between controls and cement mill workers.

Surface electromyography of intercostal muscles obtained during the inspiratory phase

Table 3 presents the mean values of various parameters obtained from SEMG of intercostal muscles in inspiratory phase for the total number of cement mill workers and

Table 2. The comparison of lung function parameters between cement mill workers and controls (n = 50)

Parameters	Control subjects (mean ± SEM)	Cement mill workers (mean ± SEM)	Significance level
FVC (litres)	4.03 ± 0.09	3.18 ± 0.11	(p < 0.0005)
FEV1 (litres)	3.04 ± 0.08	2.54 ± 0.10	(p < 0.0005)
FEV1/FVC (%)	75.84 ± 1.38	81.46 ± 2.26	(p < 0.025)
PEF (l/min)	361.72 ± 15.89	296.56 ± 18.45	(p < 0.005)
FEF25–75% (l/s)	3.31 ± 0.16	3.26 ± 0.18	NS
MVV (l/min)	114.2 ± 3.05	95.48 ± 3.79	(p < 0.0005)

NS – Non significant. SEM – Standard error of the mean.

controls. According to the comparison of the average values of various parameters between cement mill workers and controls, a statistically significant reduction in the mean values of NOP, MPA, PPA, DOR and MPD were observed in cement mill workers.

Table 3. The comparison of surface electromyography parameters between cement mill workers and matched controls in the inspiratory phase (n = 50)

Parameters	Control subjects (mean ± SEM)	Cement mill workers (mean ± SEM)	Significance level
Number of peaks	13.52 ± 0.80	7.70 ± 0.37	(p < 0.0005)
Maximum peak amplitude (mV)	0.31 ± 0.02	0.13 ± 0.01	(p < 0.0005)
Peak to peak amplitude (mV)	0.62 ± 0.04	0.26 ± 0.02	(p < 0.0005)
Duration of response (mS)	1.10 ± 0.07	0.76 ± 0.04	(p < 0.0005)
Maximum peak duration (mS)	0.067 ± 0.001	0.060 ± 0.001	(p < 0.0005)

SEM – Standard error of the mean.

Table 4. The comparison of surface electromyography parameters between cement mill workers and matched controls in the expiratory phase (n = 50)

Parameters	Control subjects (mean ± SEM)	Cement mill workers (mean ± SEM)	Significance level
Number of peaks	13.26 ± 0.74	7.12 ± 0.45	(p < 0.0005)
Maximum peak amplitude (mV)	0.29 ± 0.02	0.13 ± 0.01	(p < 0.0005)
Peak to peak amplitude (mV)	0.59 ± 0.04	0.25 ± 0.025	(p < 0.0005)
Duration of response (mS)	1.08 ± 0.06	0.75 ± 0.035	(p < 0.0005)
Maximum peak duration (mS)	0.066 ± 0.001	0.061 ± 0.001	(p < 0.0005)

SEM – Standard error of the mean.

Surface electromyography of intercostal muscles obtained during the expiratory phase

Table 4 summarizes the comparison of different SEMG parameters of intercostal muscles in expiratory phase for the total number of cement mill workers and their matched controls. In cement mill workers significant reduction was found compared with their respective controls in the mean values of NOP, MPA, PPA, DOR and MPD.

Table 5 shows the regression analysis between lung function indices and SEMG parameters of intercostal muscles obtained during expiratory phase in control subjects and cement mill workers. In the present study, significant positive correlation was found between NOP and FVC, NOP and FEV_1, NOP and PEF, NOP and MVV, DOR and FVC, and DOR and PEF in control subjects, and NOP and FVC and DOR and PEF in cement mill workers. The correlation between lung function and SEMG parameters was better related in control subjects than in cement mill workers.

Table 5. Regression analysis between lung function and surface electromyography parameters in controls and cement mill workers in the expiratory phase

Parameters	Correlation coefficient	r^2
	Control subjects	
NOP *v* FVC	0.320	0.1028
NOP *v* FEV1	0.302	0.0912
NOP *v* PEF	0.323	0.10 44
NOP *v* MVV	0.299	0.0898
DOR *v* FVC	0.272	0.0745
DOR *v* PEF	0.294	0.0869
	Cement mill workers	
NOP *v* FVC	0.296	0.0878
DOR *v* PEF	0.270	0.0732

DISCUSSION

Occupational and environmental exposure to dust particles and their effects on health is an important problem, especially in developing countries because of the lack of medical education and facilities. In addition, the systematic record-keeping and the difficulty in obtaining measurements at worksites are major hindrances [24] that have made epidemiological research difficult in these countries. However, an attempt has been made to carry out such research by overpowering the difficulties to observe the effects of cement dust on the lung functions and associated performance of respiratory muscles (intercostals). In this study, important lung function parameters, determined by spirometery, were observed to distinguish between the obstructive and restrictive pattern of lung diseases and severity of lung function impairment. In addition to lung function parameters, an integrated approach has been made to assert the involvement of respiratory muscle. Therefore, SEMG of intercostal muscle was used for indicating the pulmonary impairment in cement mill workers. The movement in the thoracic cage is the resultant of the number of factors, which include forces exerted by the respiratory muscles and the elasticity of lung and thoracic cage. A number of clinical conditions can be related to hypoventilation due to reduced strength of respiratory muscles. The weakness in respiratory muscles causes hypodynamic type of ventilatory defect, affecting the lung volumes. The decreased expansion of the lung can lead to small atelactase with reduction in lung surfactant production. These changes alter the shape of the lung regarding the volume-pressure curve and lung compliance. The respiratory muscles weakness can be diagnosed by using one of the less invasive procedures like spirometery and electromyography [19]. A number of studies have been attempted to evaluate the effects of exposure to cement dust on pulmonary functions by considering a very few parameters of spirometry and without considering a non-invasive methods like surface electromyography of respiratory muscles.

Lung function parameters

A significant reduction in the mean value of FVC and FEV_1 (Table 2) in cement mill workers compared to their matched controls is shown in the present study and this confirms the earlier studies [1,5,25–27]. One the contrary, Rasmussen et al. [28] and Abrons et al. [29] found no difference in the mean values of FVC and FEV_1 between cement mill workers and their control subjects. A probable reason for this difference in the above two reports could be the difference in the selection criteria of control subjects. Abrons et al. [29] selected blue-collar workers as control subjects from machine shops and a machinery manufacturing plant, manufacturing electric and electronic equipment. Similarly Rasmussen et al. [28] also selected the blue-collar control subjects. There is a possibility that these blue-collar control subjects are at risk regarding pulmonary function impairment.

Saric et al. [30] demonstrated that the lung function indices FVC and FEV_1 fell in cement mill workers relative to controls, but the difference was not statistically significant. However, our results showed a significant decrease in FVC and FEV_1 in cement mill workers. A probable reason for this difference could lie again in the selection criteria. Saric et al. [30] actually compared one hundred and sixty cement mill workers with eighty two shipbuilding workers. The shipbuilding workers are in general also at risk and have decreased pulmonary functions due to their work environment.

In addition, the present study reports equally reduced FVC and FEV_1 (Table 2) in cement mill workers. It is suggested that these expiratory volumes are decreased possibly due to irritant effects of cement dust [26] on respiratory apparatus or could be due to structural restrictive changes in the lung tissue [31].

Kalacic [32] reported that a restrictive ventilatory change appears in cement mill workers. These changes were less prominent initially and become prominent at later stages. In addition, Oleru [1] reported that a large number of cement mill workers suffered from restrictive type of lung disease. The present study also suggests restrictive type of pattern with significantly decreased FVC, FEV_1 with an increase in FEV_1/FVC ratio in cement mill workers. In restrictive lung disorders the forced vital capacity is reduced, but does not slow its delivery, so that FEV_1 is similarly reduced, but FEV_1/FVC ratio remains normal or increased. The present study also confirms the report of Kalacic [32] and Oleru [1].

In our results, $FEF_{25-75\%}$ was not significantly decreased in cement mill workers, while the reports of Mengesha and Bekele [33] showed a significant decrease in this parameter. However, significantly reduced PEF (Table 2) observed in the present study was similar to that reported by these authors [33].

MVV is an important parameter in the lung function, evaluated in the present study, but has not been usually taken into account in the cases of exposure to cement dust. MVV tests the overall functions of the respiratory system, respiratory muscle weakness, airway resistance, compliance of lung and chest wall [34]. It also reflects the respiratory restriction, respiratory muscle weakness and also airway obstruction [35]. Aldrich [36] reported that a severe reduction in MVV suggest an inter-current problems, such as airway obstructions, muscle dysfunction and advanced interstitial disease. In the present study, we found a significant reduction in MVV (Table 2) in cement mill workers. This finding confirmed the general relations described by Aldrich et al. [36].

SEMG parameters

In the present study, the results of SEMG parameters of intercostal muscles, NOP, MPA, PPA, DOR and MPD demonstrated significant reduction ($p < 0.0005$) during the inspiratory, as well as expiratory phases in cement mill workers compared to their matched control subjects (Tables 3 and 4). The measurement of the respiratory muscle strength is important for chest physicians, because if no pulmonary cause can be detected, the disorder may be due to respiratory muscle weakness [37]. Even moderately severe muscle weakness may be difficult to detect clinically [38]. EMG techniques have been used for monitoring the force output [39]. EMG signals recorded are usually related to their mechanical output in terms of magnitude [40]. These recorded signals with surface electrodes provide electrical information related to a number of experimental muscles performing mechanical action with respect to their motor unit activity. It has been suggested that the amplitude of electromyographic potential should be proportional to the number and activity of muscle fiber [41].

More [42] reported that the theoretical basis for an increase in surface EMG amplitude is actually an increase in the square root of muscle force. However, the increasing force may also accompany the increase in EMG potentials and the declining force may accompany the reduction of EMG potentials. It is therefore, possible that a decrease in MPA and PPA in our results may also be associated with a decreased force production. However in the present study, muscle force was not measured, but decreased myo-electrical signals reflected the decreased mechanical activity [42] of intercostal muscles.

In addition to the effects of cement dust on the respiratory system, Pimentel and Menezes [43] describe the diffuse swelling and proliferation of sinusoidal (hepatic) lining cells, sarcoid type granulomas, perisinusoidal and portal fibrosis in cement mill workers, and they also found abundant inclusions of the inhaled material within the pulmonary and hepatic lesions. In their opinion [43], the inhaled cement particles reach the liver by the blood stream and produce different types of lesions.

Reichrtova [44] found the bioaccumulation of industrial cement dust components in laboratory animals exposed by inhalation to cement emission and reported that the chemical components of the cement dust particles inhaled by animals are accumulated not only in lungs, but also in other organs, bones and hair of the exposed animals.

Maciejewska [45] induced 50 mg of siliceous dust by intra-tracheal administration in rats and tested the affected rats. She found an increased level of collagen due to fibrosis in the heart and spleen of the rats. This animal study findings show that silica is deposited in the heart, as well as in the spleen when introduced by intra-tracheal route and causes fibrosis, hence the collagen contents are increased in these organs. In addition, Gościcki et al. [46] reported that exposure to cement dust causes fibrogenic properties in animals.

Hogue et al. [2] showed that cement dust is the source of selenium, they included selenium in the feed of sheep for five months only and found an increased level of selenium in the blood and tissues of sheep.

Pond et al. [47] added the cement kiln dust (CKD) in the feed of weanling pig in a-42 day experiment and found that the body weight gain was depressed. They also observed lesions of the humerus bone along with osteonecrosis, thinning of cortex and reduction of epiphyseal cartilage.

Brockhaus et al. [3] reported that thallium containing atmospheric dust caused by emission of the cement plant affects the population living around the cement plant and exhibited the increased urinary concentration and the enhanced level of thallium in hair of the subjects living around the cement plant. Similarly, Dolgner et al. [48] reported that thallium dust is generated during cement production and affects the population living in the cement plant vicinity, inducing the increased urinary concentration and also congenital malformations.

On the basis of the reports of Pimentel and Menezes [43], Reichrtova [44], Maciejewska [45], Hogue et al. [2], Pond et al. [47], Brockhaus et al. [3] and Dolgner et al. [48], it is suggested that when the components of cement dust enter into the blood stream and find themselves in the heart, liver, spleen, bones and hair, they may also reach different tissues of the body, including skeletal muscles, and affect their microstructure and physiological performance. In the present study, the experiments on intercostal muscles exhibit that the reduced performance due to cement dust is probably associated with the changes in the muscle structure and chest cage compliance. In addition, the positive correlation between various lung functions and SEMG parameter in controls and cement mill workers shows that the lung function parameter obtained by spirometry, and SEMG parameter recorded from intercostal muscles are correlated with each other.

Our results suggest that exposure to cement dust not only impairs lung function but also affects costal muscle performance, thus possibly decreasing the lung compliance, as well as the chest wall compliance. We further suggest that histopathological studies will be helpful in determining the pathological effects of cement dust on skeletal muscles.

Cement industry workers should wear protective clothing, safety goggles and be subjected to compulsory pre-employment and periodic medical surveillance, especially the spirometry. These measures would help to identify susceptible workers in due time and improve the technical preventive measures that will decrease the risk of occupational hazards in the cement industrial workers.

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Received for publication: February 11, 2002
Approved for publication: July 15, 2002