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Dose response effect of cement dust on respiratory muscles competence in cement mill workers

SULTAN A. MEO[1], MUHAMMAD A. AZEEM[2], AIJAZ A. QURESHI[3], G. MOINUDIN GHORI[4], ABDUL MAJEED AL-DREES[5], & MIRZA MUHAMMAD FEISAL SUBHAN[6]

[1]*Department of Physiology, Faculty of Health and Medical Sciences, Hamdard University,* [2]*Department of Physiology, University of Karachi, Pakistan,* [3]*Department of Physiology, Sindh Medical College,* [4]*Department of Physiology, Karachi Medical & Dental College, Pakistan,* [5]*Department of Physiology, College of Medicine, KSU, and* [6]*Department of Biological & Bio Medical Sciences, Aga Khan University, Karachi, Pakistan*

Abstract
Electromyography (EMG) of respiratory muscles is a reliable method of assessing the ventilatory muscle function, but still its use has not been fully utilized to determine the occupational and environmental hazards on respiratory muscles. Therefore, EMG of intercostal muscles was performed to determine the dose response effect of cement dust on respiratory muscles competence. Matched cross-sectional study of EMG in 50 non-smoking cement mill workers with an age range of 20–60 years, who worked without the benefit of cement dust control ventilation or respiratory protective devices. EMG was performed by using surface electrodes and chart recorder. Significant reduction was observed in number of peaks ($p < 0.0005$), maximum peak amplitude ($p < 0.0005$), peak-to-peak amplitude ($p < 0.0005$) and duration of response ($p < 0.0005$) in cement mill workers compared to their matched control. Cement dust impairs the intercostal muscle competence and stratification of results shows a dose-effect of years of exposure in cement mill.

Keywords: *Electromyography, cement dust, respiratory muscles competence*

Introduction

Cement mill workers are exposed to dust at various manufacturing and production processes such as during quarrying and handling of raw materials, grinding the clinker, blending, packing and shipping of the finished products (Abudhaise et al. 1997). Portland cement dust is a mixture of calcium oxide, silicon oxide, aluminum tri-oxide, ferric oxide, magnesium oxide (Oleru 1984), selenium (Hogue et al. 1981), thallium and also other impurities (Brockhaus et al. 1981).

Correspondence: Dr Sultan Ayoub Meo, MBBS MPhil PhD, Associate Professor, Department of Physiology (29), College of Medicine, King Khalid University Hospital, KSU, PO Box 2925, Riyadh 11461, Kingdom of Saudi Arabia. Tel: +9661 4671604. Fax: +9661 4672567. E-mail: sultanmeo@hotmail.com

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Occupational exposure to cement dust may cause numerous health problems which may result in functional and structural abnormalities (Short & Petsonk 1996). Most of the organs of cement mill workers are exposed to dust, but the respiratory system is more prone to exposure to cement dust. It has been also reported that cement dust would tend to accumulate in the alveoli and with the passage of time also be deposited in the liver, spleen, bones and hairs and cause structural and functional abnormalities (Brockhaus et al. 1981; Hogue et al. 1981; Aminoff 1987; Maciejewska 1987; Stalberg & Falck 1997). The most frequently reported health problems in cement mill workers are chronic cough and phlegm production, impairment of lung function, chest tightness, obstructive and restrictive lung disease, skin irritation, conjunctivitis, stomach ache, headache, fatigue and carcinoma of larynx, lung, stomach and colon (Abou Taleb et al. 1995; Rafnsson et al. 1997; Dietz et al. 2004; Meo 2004).

The lung and its diseases has traditionally been the focal point of interest, whereas pump disorders (respiratory muscles and the chest wall) have received appallingly little attention. The respiratory muscles especially the diaphragm and intercostal muscles play a significant role in breathing, and subjects with respiratory muscle weakness breath faster with a smaller tidal volume. The respiratory muscles, particularly those of inspiration can be affected and precipitate or intensify ventilatory failure (Koulouris et al. 2001). Effects of cement dust on the respiratory apparatus has been observed by using spirometry and/or radiology without observing its effects on the respiratory muscles by considering electromyography (EMG). In spite of development of new methods such as histochemistry, biochemistry and genetics, EMG still has an important part of the study of normal and abnormal nerves and muscles and in the evaluation of patients with neuromuscular disorders (Dyck et al. 1996; Mastaglia & Laing 1996). It is also regarded as an electrophysiological counterpart to the morphological techniques used like biopsy, radiology and computerized tomographic scan for the detection of various neuromuscular disorders (Rostedt et al. 2005). In addition, EMG has also been used to investigate the activity of the diaphragm and intercostal muscles (Maarsingh et al. 2000).

Keeping in view the sensitivity of this major public health problem and realizing the significance of respiratory muscles EMG, it is worthwhile to use the applications of EMG in occupational and environmental health and investigate the dose-response relationship between years of exposure to cement dust and respiratory muscles competence. The present study attempts to minimize confounding interpretational factors by using matched controls, excluding smokers and workers with previous industrial exposure other than cement industries.

Subjects and methods

Subjects

The author visited the cement industry located at Mangoper, Karachi, Pakistan, and interviewed approximately 105 cement mill workers. A comprehensive history was taken to determine whether they would be included in the study or not on the basis of the exclusion criteria. All the participants were clinically examined and questioned with regards to smoking cigarettes and other tobacco products and chewing tobacco or betel nut products. After the initial interviews 50 apparently healthy male cement mill workers with age 36.86 ± 1.50 years (mean $\pm$ SEM; range 20–60 years) were selected and further divided into three groups based on the duration of exposure less than 5, 5–10 and greater than 10 years. The mean duration of exposure in cement mill workers was $3.30 + 0.26$ years (mean $\pm$ SEM), range 2–4 years; 7.30 ± 0.47 years (mean $\pm$ SEM) range 6–10 years; 18.0 ± 0.70 years (mean $\pm$ SEM) range

11 – 28 years, respectively. Cement mill workers worked for at least 8 – 10 h a day for six days per week, without using any adequate personal protective measures. The control group was selected in a similar way from approximately 80 interviewed subjects, comprising finally 50 matched healthy men, mean age 37.80 $\pm$ 1.66 years (mean $\pm$ SEM) range 20 – 60 years. The control group was composed primarily of clerical staff, shopkeepers and salesmen. All subjects were individually matched for age, height, weight, and socio-economic status. The Ethics Committee, Hamdard University, approved the study.

Exclusion criteria

Subjects with clinical abnormalities of the vertebral column, thoracic cage, neuromuscular diseases, known cases of gross anemia, diabetes mellitus, pulmonary tuberculosis, bronchial asthma, chronic bronchitis, bronchiectasis, emphysema, malignancy, drug addicts, cigarette smokers, tobacco chewers, those who had undergone vigorous exercise, abdominal, or chest surgery, and subjects exposed in any industry other than cement industry were also excluded from the study.

Methods

For recording the electromyogram, the experimental set-up included two-channel chart records, isolated preamplifier, surface electrodes, gel and skin cleansing material (razor and spirit-swab) and the EMG was performed by using surface electrodes and Lafayette instrument (Model 76107 USA) at a fixed time of the day (9:00 – 13:00 h). After cleansing and counting the intercostal space, surface electrodes were applied on the 7th and 8th right side intercostal spaces (Meo et al. 2002). Before recording, the frequency and gain of the isolated preamplifier was adjusted. In order to check that the EMG signals were properly recorded, the subjects were asked to deeply inspire and deeply expire though avoiding unnecessary body movements. For each subject, 4 – 5 observations were recorded with the speed of 25 mm/sec. At the end of the experiment an internal calibration signal of 1-mV was obtained for the quantification of the EMG signal for analysis. The parameters measured from the surface electromyography (SEMG) records, using calibration for amplitude & paper speed were, number of peaks (NOP), maximum peak amplitude (MPA), peak-to-peak amplitude (PPA) and duration of response (DOR).

Analysis

Statistical analysis was conducted using a paired t-test (two-tailed). The level of significance was taken as $p < 0.05$. Analysis of variance (ANOVA) was designed by two-factor factorial in completely randomized data was performed by using a computer on Stat pac Gold statistical analysis package.

Results

Surface electromyography (SEMG) of intercostal muscles during inspiratory phase: Duration of exposure less than 5, 5 – 10 and greater than 10 years

Tables I – III summarize the comparison of the anthropometric and EMG parameters between cement workers with duration of exposure less than 5 (Table I); 5 – 10 (Table II) and greater than 10 (Table III) years compared with their matched controls. There was no

Table I. Surface electromyography (SEMG) of intercostal muscles during inspiratory phase: anthropometric and EMG parameters for cement mill workers with duration of exposure <5 years compared with their matched controls.

Parameters	Control subjects (mean ± SEM) ($n = 10$)	Cement mill workers (mean ± SEM) ($n = 10$)	Significance level
Age (years)	26.50 ± 2.88	25.20 ± 2.33	NS
Height (cm)	168.10 ± 1.37	166.90 ± 1.61	NS
Weight (kg)	62.70 ± 3.18	60.70 ± 2.74	NS
Number of peaks	15.39 ± 1.65	7.88 ± 0.96	$p < 0.0005$
Maximum peak amplitude (mV)	0.37 ± 0.06	0.11 ± 0.02	$p < 0.0005$
Peak-to-peak amplitude (mV)	0.72 ± 0.11	0.24 ± 0.04	$p < 0.0005$
Duration of response (mS)	1.23 ± 0.13	0.72 ± 0.07	$p < 0.0005$

NS, non-significant.

Table II. Surface electromyography (SEMG) of intercostal muscles during inspiratory phase: anthropometric and EMG parameters for cement mill workers with duration of exposure 5–10 years compared with their matched controls.

Parameters	Control subjects (mean ± SEM) ($n = 10$)	Cement mill workers (mean ± SEM) ($n = 10$)	Significance level
Age (years)	34.30 ± 3.75	32.70 ± 3.40	NS
Height (cm)	165.30 ± 2.26	166.20 ± 2.00	NS
Weight (kg)	66.10 ± 2.18	62.90 ± 2.51	NS
Number of peaks	14.69 ± 2.35	7.61 ± 0.70	$p < 0.005$
Maximum peak amplitude (mV)	0.28 ± 0.06	0.15 ± 0.02	$p < 0.025$
Peak-to-peak amplitude (mV)	0.55 ± 0.13	0.30 ± 0.04	$p < 0.05$
Duration of response (mS)	1.20 ± 0.19	0.79 ± 0.09	$p < 0.05$

NS, non-significant.

Table III. Surface electromyography (SEMG) of intercostal muscles during inspiratory phase: anthropometric and EMG parameters for cement mill workers with duration of exposure >10 years compared with their matched controls.

Parameters	Control subjects (mean ± SEM) ($n = 30$)	Cement mill workers (mean ± SEM) ($n = 30$)	Significance level
Age (years)	42.73 ± 1.75	42.13 ± 1.37	NS
Height (cm)	164.27 ± 1.19	165.03 ± 1.17	NS
Weight (kg)	63.27 ± 1.34	64.97 ± 1.97	NS
Number of peaks	12.51 ± 0.92	7.67 ± 0.49	$p < 0.0005$
Maximum peak amplitude (mV)	0.31 ± 0.02	0.13 ± 0.01	$p < 0.0005$
Peak-to-peak amplitude (mV)	0.62 ± 0.05	0.25 ± 0.03	$p < 0.0005$
Duration of response (mS)	1.01 ± 0.09	0.76 ± 0.06	$p < 0.025$

NS, non-significant.

significant difference between the means of any anthropometric parameters in terms of age, height or weight between both groups. However, in cement mill workers with a period of exposure, statistically significant decline was demonstrated in the values of EMG parameters, NOP, MPA, PPA, and DOR compared to control group as indicated in Tables I–III. The mean duration of exposure in these cement mill workers was 3.30 ± 0.26 years (mean ± SEM), range 2–4 years, 7.30 ± 0.47 years range 6–10 years and 18.0 ± 0.70 years range 11–28 years, respectively.

Surface Electromyography (SEMG) of intercostal muscles during expiratory phase

Tables IV–VI summarize the different parameters of EMG between cement mill workers during expiratory phase on the basis of duration of exposure less than 5, 5–10 and greater than 10 years compared with their matched controls. According to the mean values presented

Table IV. Surface electromyography (SEMG) of intercostal muscles during expiratory phase: EMG parameters for cement mill workers with duration of exposure <5 years compared with their matched controls.

Parameters	Control subjects (mean ± SEM) ($n = 10$)	Cement mill workers (mean ± SEM) ($n = 10$)	Significance level
Number of peak	15.13 ± 1.42	6.04 ± 0.64	$p < 0.0005$
Maximum peak amplitude (mV)	0.34 ± 0.065	0.14 ± 0.02	$p < 0.005$
Peak-to-peak amplitude (mV)	0.67 ± 0.11	0.26 ± 0.04	$p < 0.005$
Duration of response (mS)	1.20 ± 0.09	0.69 ± 0.05	$p < 0.0005$

Table V. Surface electromyography (SEMG) of intercostal muscles during expiratory phase: EMG parameters in cement mill workers with duration of exposure 5–10 years compared with their matched controls.

Parameters	Control subjects (mean ± SEM) ($n = 10$)	Cement mill workers (mean ± SEM) ($n = 10$)	Significance level
Number of peak	13.59 ± 2.06	7.2 ± 0.68	$p < 0.005$
Maximum peak amplitude (mV)	0.33 ± 0.07	0.191 ± 0.04	$p < 0.05$
Peak-to-peak amplitude (mV)	0.60 ± 0.11	0.35 ± 0.07	$p < 0.05$
Duration of response (mS)	1.07 ± 0.16	0.77 ± 0.05	$p < 0.05$

Table VI. Surface electromyography (SEMG) of intercostal muscles during expiratory phase: EMG parameters in cement mill workers with duration of exposure >10 years compared with their matched controls.

Parameters	Control subjects (mean ± SEM) ($n = 30$)	Cement mill workers (mean ± SEM) ($n = 30$)	Significance level
Number of peak	12.53 ± 0.91	7.46 ± 0.69	$p < 0.0005$
Maximum peak amplitude (mV)	0.27 ± 0.02	0.11 ± 0.01	$p < 0.0005$
Peak-to-peak amplitude (mV)	0.56 ± 0.05	0.22 ± 0.02	$p < 0.0005$
Duration of response (mS)	1.053 ± 0.08	0.76 ± 0.05	$p < 0.005$

with the duration of exposure in cement mill workers a statistically significant reduction has been demonstrated in the mean values of NOP, MPA, PPA and DOR, from their control.

Two-way analysis (ANOVA)

Two-way analysis (ANOVA) was performed to observe the relationship between dose effect of cement dust and age between the groups. The present study results showed that, NOP ($p < 0.0005$, duration effect; $p = 0.88$, age effect); MPA ($p < 0.0005$, 0.24); PPA ($p < 0.0005$, 0.45) and DOR ($p < 0.0005$, 0.91) were significantly decreased due to dose affects of cement dust, however, no significant difference was observed due to age between the groups.

Discussion

Respiratory muscle strength/endurance is of interest in pulmonary, critical care and many other areas of medicine. The capacity of the respiratory muscle pump to respond to the load imposed by disease is the basis of an understanding of ventilatory failure. Severe weakness of respiratory muscles and decreased endurance may result in respiratory failure. Respiratory muscles weakness is associated with poor quality of life and respiratory disorders (Syabbalo 1998) and magnitude of muscle weakness may be difficult to perceive clinically (Lin & Lim 2005). EMG is used to detect the strength of contraction, force output and pressure changes (Maul et al. 2004; Shafik et al. 2006) and their signals are related to their mechanical output in provisions of magnitude. The EMG signals provide electrical information related to a number of muscles performing mechanical action with respect to their motor unit activity, and amplitude of EMG potential is proportional to the number and activity of muscle fibers. Furthermore, the EMG is a valuable tool in functional studies of intra-and inter-muscular movement coordination (Grassme et al. 2005).

In the present study the EMG parameters (NOP, MPA, PPA, and DOR) were analysed on the basis of duration of exposure to cement dust, i.e. <5 years, 5 – 10 years and >10 years. In cement mill workers EMG parameters in inspiratory and expiratory phase were significantly decreased with <5 years of exposure. In addition, EMG parameters observed in cement mill workers with 5 – 10 year of exposure, the significant difference for all EMG parameters was less as compare to workers having <5 years of exposure. This decrease in significance level of various EMG parameters during 5 – 10 years of exposure was not expected. However, a possible compensatory response has been suggested regarding the activity of intercostal muscles when the period of exposure is increasing from less than 5, 5 – 10 years. Due to compensatory mechanism these muscles produce a better response, which was observed as an improved value of EMG parameters obtained from costal muscle performance. However, the significance level was again increased for NOP, MPA, PPA and DOR, indicative of a reduced in muscle performance in cement mill workers with duration of exposure > 10 years compared with controls.

Hypertrophy can be caused by increased functional demand and may occur under both physiological and pathological conditions (Abou Taleb et al. 1995). It has been reported that muscle hypertrophy of physiological type may develop in the course of certain respiratory disease such as chronic obstructive pulmonary disease and physiological states. Levine et al. (1997) reported that, in chronic obstructive pulmonary disease the strength of the respiratory muscles was preserved, most probably due to hypertrophic response and hypertrophied muscles produce better performance. Our suggestion regarding compensatory response of intercostal muscles confirms the description of Levine et al. (1997).

Huo et al. (1994) studied patients with pulmonary fibrosis and reported that the EMG activity of intercostal muscles was increased when patients are in compensatory stage and they also reported that the patients with serious respiratory impairment have a remarkably decreased EMG amplitude. Our results regarding compensatory response of intercostal muscles confirm the results of Huo et al. (1994).

Valli et al. (1984) reported that patients with respiratory insufficiency had reduced amplitude of compound action potential. Similarly, our results showed that cement dust causes respiratory insufficiency, hence the EMG parameters are significantly decreased compared to their control subject.

Linnamo et al. (2001) observed the characteristics of the electromyogram (EMG) power spectrum, such as the median or the mean power frequency, as well as the duration of the muscle compound action potential response; their results suggested that EMG increased with increase in force. It shows that EMG amplitude is actually an increase in the square root of muscle force. However, increasing force may also accompany the increase in the EMG potentials and declining force may accompany the reduction of EMG potentials. It is therefore, possible that a decrease in MPA and PPA in the present study results for cement mill workers may also be associated with a decreased force production. Although, in the present study, muscle force was not measured but decreased myo-electrical signals reflect decreased mechanical activity (Linnamo et al. 2001) of intercostal muscles. Similarly, a decrease in NOP and DOR in the present study results for cement mill workers may also be associated with a decreased motor unit activity.

Meo et al. (2002) demonstrated that cement dust not only impairs the lung functions but also affects the intercostal muscles' performance. Similarly, in the present study, we observed that increased duration of exposure to cement dust further impairs the respiratory muscles functional capability.

Pimentel and Menezes (1978) found inclusions of the inhaled material within the pulmonary and hepatic lesions. In their opinion, the inhaled cement particles deposit in the lungs and reach the liver by the blood stream and produce different types of lesions. In addition, Reichrtova (1986) reported that the chemical components of the cement dust particles inhaled by animals are accumulated not only in lungs, but also in bone and hairs of the exposed animals. Maciejewska (1987) showed that the silica is deposited in the heart as well the spleen when introduced by intra-tracheal route and causes fibrosis. In addition, Pond et al. (1982) added the cement kiln dust (CKD) in animal feed and found lesions of the humerus bone along with osteonecrosis, thinning of cortex and reduction of epiphyseal cartilage. In addition, Brockhaus et al. (1981) and Dolgner et al. (1983) reported that thallium containing atmospheric dust caused by emission of a cement plant affects the population living around the plant and subjects exhibited increased urinary thallium concentration as well increased thallium level in hair. It is important to note that the intercostal muscles might be equally affected on exposure of the subject with cement dust as already reported for lungs, heart, liver, spleen, bone and hair (Pimentel & Menezes 1978; Brockhaus et al. 1981; Hogue et al. 1981; Pond. et al. 1982; Dolgner et al. 1983; Reichrtova 1986; Maciejewska 1987).

Conclusion

In the present study it has been observed that exposure to cement dust impairs the intercostal muscles' functional capability and respiratory muscles function is decreased with increased duration of exposure to cement dust. The aforementioned facts allow us to conclude that when the components of cement dust enter into the bloodstream and find themselves in the heart, liver, spleen, bones and hair, they may also reach into the other tissues including respiratory muscles and affect their microstructure and physiological competence. In cement mill workers, EMG parameters in inspiratory and expiratory phase were significantly decreased with duration of exposure. However, at shorter duration of exposure a compensatory response was observed to maintain the respiratory function but respiratory muscles failed to maintain the compensatory response for prolonged periods of exposure to cement dust. Our result on intercostal muscles demonstrates that the decline presentation is most probably associated with changes in the muscles structure and chest cage compliance. It is advisable, therefore, that heath risk should be reduced by mutual collaboration between health officials, cement industry management and their workers in the areas of implementation of protective measures, such as improvement of ventilation and workers should wear appropriate clothing, mask and safety goggles. It is also suggested that cement mill workers should undergo pre-employment and periodic medical surveillance tests and the applications of EMG should be used to rule out the respiratory muscles disorders in the industrial sectors to prevent early respiratory pump failure due to respiratory muscles damage. These measures will help to identify susceptible workers in time and improve the technical preventive measures that will decrease the risk of occupational and environmental hazards in the cement industry workers.

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