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The effect of chronic exposure to flour dust on pulmonary functions

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Purpose. This study aimed to examine the effect of chronic exposure to flour dust on the pulmonary symptoms and pulmonary indices of mill workers. *Methods.* The cohort study was conducted on 67 mill workers and 53 controls from 2014 to 2016. Demographic information was collected through interviews and pulmonary indices; flour dust exposure was measured by spirometry, and NIOSH 0500 and NIOSH 0600 methods. *Results.* The incidences of pulmonary symptoms, including cough, sputum, dyspnea, wheezing and bronchitis, were significantly more in the case group than the control group. At the beginning of the study, there was no significant difference between the case and control groups regarding the pulmonary indices of forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1), peak expiratory flow and FEV_1/FVC; however, after 2 years of exposure to flour dust, the pulmonary indices significantly decreased in the case group and showed a restrictive pattern. Based on the linear regression model, the most important predictor variables of FVC and FEV_1 were age, body mass index, smoking and level of exposure to respirable flour dust. *Conclusions:* There is a strong correlation between chronic exposure to flour dust and the incidence of pulmonary complications and reduced pulmonary functions.

Keywords: cohort study; pulmonary symptoms; restrictive pattern

1. Introduction

Flour dust is widely recognized as one of the most important causes of pulmonary dysfunction [1]. The content of wheat flour significantly contributes to its harmful effects. Wheat flour is a complex, allergenic dust, which contains various types of antigenic and allergic compounds [2]. The major proteins found in wheat flour include salt-soluble globulins, water-soluble albumins, glutens and gliadins, which are effectively involved in the development of pulmonary function disorders. Gliadins and glutelins, which make up about 80% of wheat flour proteins [3,4], play an effective role in allergic diseases. Also, albumins and globulins are the major contributing proteins in hypersensitivity reactions to flour dust [5,6]. In addition to proteins, the contaminants associated with flour, like parasites, insects and fungi, and its metabolites (aflatoxin), silica, bacterial endotoxins and various chemical additives such as insecticides and herbicides can exacerbate the adverse pulmonary effects [7,8]. A wide range of employees and workers in various food industries, including traditional and industrial bakeries, producing biscuits, cakes, pasta and pizza, and grain mill workers are occupationally exposed to flour dust [9]. In 2011, the threshold limit value for flour dust was recommended to be 0.5 mg/m^3 by the American Conference of Governmental Industrial Hygienists (ACGIH) [10], which has also been accepted by the Iranian Center for Environmental and Occupational Health. This was the exposure level in the respiratory region for flour mill industry workers.

However, allergic rhinitis, chronic bronchitis, decreased pulmonary function, sensitivity reactions and occupational asthma are still the most important pulmonary diseases among bakers and mill workers and those exposed to flour dust [11,12]. Flour mill employees report various clinical symptoms, including wheezing, febrile reactions, grain fever, pulmonary fibrosis, allergic alveolitis, pulmonary dysfunction and chronic obstructive pulmonary disease [13,14]. The spirometric results of these workers might show a significant decrease in pulmonary parameters, including forced vital capacity (FVC), peak expiratory flow (PEF) and forced expiratory volume in one second (FEV_1); and most of these workers suffer from asthma and respiratory problems [15,16]. Dust particles can stick to the upper respiratory pathways and interfere with inhalation and exhalation. Dust particles can cause irritation in the respiratory tracts and are associated with the early signs of pulmonary disease [17].

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Although pulmonary diseases develop over long time periods, most previous studies on the adverse pulmonary effects of flour dust exposure have been cross-sectional. In addition, measuring exposure to flour dust can be significantly influenced by environmental conditions such as temperature, pressure and air flow, as well as the time of measurement. In this study, the effect of long-term exposure to flour dust on pulmonary indices and symptoms was evaluated.

2. Methods

The current cohort study was performed on the workers of wheat mills in Kerman, Iran from 2014 to 2016. Participants were enrolled according to inclusion and exclusion criteria. The inclusion criteria involved work experience of at least 5 years at the mill and working 8–10 h/day, 6 days/week. The exclusion criteria included having a second job and lung injuries due to accidents. Also, those who did not accept signing a written consent to participate in the study were excluded. According to the inclusion and exclusion criteria, 90 people were eligible to participate in the study; however, by the time the study ended, 15 people had left their job and eight people declined to participate in the study. Eventually, 67 workers completed the study. Participants were mainly responsible for operating grinding machine and cleaning duties such as waste removal and general cleaning of the working areas at each section, while weighing flour was performed only in the packing section.

All measurements were made at two time points, September 25, 2014 (T1) and September 30, 2016 (T2). In addition to the exposed group, 53 unexposed office workers were selected as the non-exposed group who were similar in terms of job conditions but were not exposed to flour dust. These people entered the study according to the same inclusion and exclusion criteria. All participants were male.

All workers were interviewed by a physician and completed a questionnaire, including personal information and pulmonary disorders. The individual information questionnaire included questions about age, height, weight, work experience, smoking status, history of surgery, pulmonary diseases and tuberculosis, and the use of anti-allergy drugs.

A pulmonary questionnaire recommended by the American Lung Association was used to evaluate pulmonary disorders [18]. Workers were asked questions about upper respiratory symptoms, including sneezing, rhinorrhea and voice changes. Lower respiratory symptoms included cough, phlegm, shortness of breath and wheezing. Workers were also asked about any lung disease associated with their occupation.

2.1. Measuring the level of exposure to flour dust

The gravimetric method (NIOSH 0500 and NIOSH 0600) was used to measure the amount of total and respirable dust. According to the NIOSH 0500 method, a 37-mm polystyrene closed face cassette (SKC, USA) with a preweight 5-μm pore size PVC filter (SKC, USA) was used with a flow rate of 1.5 L/min, and the air sampling volume was selected based on the amount of flour dust in the air. When the level of flour dust was high, the air sampling volume was reduced to prevent loading the filter with more than 2 mg of flour dust. The air sampling volume for total dust was between 540 and 720 L.

Based on the NIOSH 0600 method, a 10-mm nylon cyclone (MSA, USA) with a PVC membrane filter (SKC, USA) and a holder was placed in the respiratory zone of the workers. Then, the respirable dust concentration was measured with a flow rate of 1.7 L/min. The air sampling volume for respirable dust was between 650 and 816 L.

In each method, a filter was placed as a control filter cassette in the working environment. Before and after sampling, each of the filters was placed in a desiccator for 8 h to remove moisture and weighed with a five-decimal microbalance (Sartorius, USA). The total and respirable dust sampling were taken for each worker simultaneously. Finally, the 8-h time-weighted average of exposure to flour dust was calculated as milligrams/cubic meter [19].

2.2. Spirometry

The spirometry test was performed for all participants using Vitalograph 2110 (Vitalograph Ltd, UK) according to standard instructions [20]. The method of testing was explained to and trained for all subjects. The test was carried out in a standing and perfectly straight position wearing a nose clip. The test was repeated three times and workers could rest by sitting on a chair after each test. The reported parameters were FVC, FEV_1, FEV_1/FVC and PEF. According to standard instructions, the highest level of parameters was chosen when the difference between the largest and the next largest FEV_1 or FVC was $\leq$0.150 L.

2.3. Ethical considerations

This study was approved by the Kerman University of Medical Sciences Ethics Committee. A letter was sent to wheat mills to seek their cooperation. The researchers also explained the objectives of the study to relevant authorities and received written permissions. Before collecting information, the study objectives were explained to each worker and, after signing the written consent form, information was collected through interviews and without recording their names. The subjects were assured that they could leave the study at any stage without trouble.

2.4. Statistical analysis

Descriptive statistics (frequency, percentage, mean and standard deviation) were used to summarize the results. The χ^2 test was used to examine the difference between the exposed and non-exposed groups. A paired *t* test was used to compare the changes in the spirometric indices at the two time periods. Multivariate linear regression was used to investigate the effect of variables (mean exposure to dust at the two time intervals, demographic variables) on the lung function change (difference in performance measured at the two time intervals). All statistical tests were performed using SPSS version 24.0 at a significance level of $p < 0.05$.

3. Results

Demographic data are presented in Table 1. Most of the participants were in the 30–40 years age group. None of the demographic variables in the exposed and non-exposed groups had a significant difference.

Measurement of flour dust exposure showed that workers were exposed to 11.06 mg/m^3 total dust. Nearly half of the mill workers (45%) were exposed to respirable flour dust higher than the standard threshold (Table 2).

Among the studied pulmonary symptoms, cough and sputum had the highest frequencies. Moreover, asthma was the least frequent condition in the groups (Table 3).

The results of the paired *t* test showed that chronic exposure to dust significantly reduced the FVC, FEV_1 and PEF, and significantly increased the FEV_1/FVC (Table 4).

The predictors of pulmonary indices using multivariate linear regression analysis are presented in Table 5. With increased age, the FVC, FEV_1 and PEF indices decreased significantly. Smoking only reduced the FVC index, significantly. There was a significant negative correlation between the amount of exposure to respirable dust and the FVC, FEV_1 and PEF indices.

Table 1. Demographic information of the case and control groups.

Variable	Classification	Frequency (%) Exposed ($n = 67$)	Frequency (%) Non-exposed ($n = 53$)
Age (years)	<30	24 (35.8)	16 (30.2)
	30–40	25 (37.3)	29 (54.7)
	>40	18 (26.9)	8 (15.1)
Body mass index	Underweight	2 (3)	1 (2)
	Normal	38 (56.7)	31 (60)
	Obese	27 (40.3)	20 (38)
Experience (years)	≥10	44 (65.7)	10 (18.9)
	>10	23 (34.3)	43 (81.1)
Smoking	Yes	13 (19.4)	11 (20.7)
	No	54 (80.6)	42 (79.3)

Table 3. Frequency (%) of symptoms and respiratory diseases among the exposed and non-exposed groups.

Symptom	Exposed group (%)	Non-exposed group (%)
Cough**	31 (46.2)	3 (5.7)
Sputum*	27 (40.3)	4 (7.5)
Dyspnea*	13 (19.4)	2 (3.8)
Wheezing*	17 (25.4)	3 (5.4)
Asthma	8 (11.9)	1 (1.9)
Bronchitis*	11 (16.4)	2 (3.8)

*$p < 0.05$; **$p < 0.005$.

4. Discussion

This was one of the first cohort studies about the effect of chronic exposure to flour dust on lung function among mill workers in Iran. Dust flour is released into the air in mills during various processes such as crushing, packing, transportation and mixing, and is known as an occupational problem. In this study, the rate of exposure to flour dust was more than the standard threshold recommended by the ACGIH in 45% of the workers. The occurrence of pulmonary symptoms like cough, sputum, dyspnea, wheezing and bronchitis in the exposure group was significantly higher than in the control group. These results were consistent with the symptoms reported in other studies among wheat mill and bakery workers [21,22]. Studies have also reported other pulmonary symptoms such as runny noses, skin rashes, chest pain, eye inflammation, pulmonary fibrosis, conjunctivitis and chronic obstructive pulmonary disease among mill workers [23,24]. Mohammadien et al. [2] found that the prevalence of upper pulmonary symptoms, including productive cough, dyspnea and wheeze, was significantly higher in mill workers than in controls. In addition, the pulmonary X-ray images showed that exposed workers had significant hyperinflation, and reticulonodular and exaggerated bronchovascular markings. Similarly, in the study by Moghaddasi et al. [25], pulmonary symptoms

Table 2. Exposure levels in the mill workers.

Variable	Classification	$M \pm SD$	ACGIH TLV† Under	ACGIH TLV† Over
Flour dust exposure (mg/m^3)	Total	11.06 ± 8.73	44 (65.6)	23 (34.4)
	Respirable	7.77 ± 8.35	36 (54.7)	31 (45.3)

†Total and flour dust threshold limit value (TLV) recommended by the ACGIH are 10 and 0.5 mg/m^3.
Note: ACGIH = American Conference of Governmental Industrial Hygienists.

Table 4. Changes in pulmonary function based on flour dust exposure.

Variable	Exposed group T1	Exposed group T2	Non-exposed group	p T1 vs T2	p T1 vs NG	p T2 vs NG
FVC	4.84 ± 1.16	4.12 ± 0.98	5.08 ± 0.21	<0.001	0.241	<0.001
FEV_1	3.87 ± 0.89	3.59 ± 0.81	3.84 ± 0.52	0.012	0.884	0.049
FEV_1/FVC	0.81 ± 0.08	0.88 ± 0.11	0.81 ± 0.059	<0.001	0.364	0.012
PEF	9.16 ± 1.62	8.21 ± 1.59	8.82 ± 1.12	<0.001	0.638	0.003

Note: Data presented as mean ± *SD*. FEV_1 = forced expiratory volume in 1 s; FVC = forced vital capacity; NG = non-exposed group; PEF = peak expiratory flow; T1 = September 25, 2014; T2 = September 30, 2016.

Table 5. Results of backward multiple linear regression to predict variables related to decreased pulmonary function.

Variable	Classification	*B*	*t*	95% CI
FVC				
Age (years)**	>40 vs >30	−0.91	−3.45	[−1.439, −0.37]
BMI	Obese vs normal	−0.41	−2.02	[−0.809, 0.003]
Smoking*	Yes vs no	−0.47	−2.06	[−0.945, −0.26]
Respirable dusts (mg/m^3)**		−0.06	−4.59	[−0.084, −0.03]
FEV_1				
Age (years)**	>40 vs >30	−0.66	−2.82	[−1.144, −0.18]
BMI*	Obese vs normal	−0.467	−2.47	[−0.855, −0.08]
Respirable dusts (mg/m^3)**		−0.04	−3.24	[−0.064, −0.01]
FEV_1/FVC				
Working years*	≥10 vs <10	−0.08	−1.89	[−0.174, 0.99]
Respirable dusts (mg/m^3)		0.005	2.45	[1.001, 0.009]
PEF				
Age (years)**	>40 vs >30	−2.56	−4.47	[−3.72, −1.38]
BMI**	Underweight vs normal	1.81	3.11	[0.61, 2.99]
Working years*	≥10 vs <10	1.23	2.21	[0.08, 2.37]
Respirable dusts (mg/m^3)*		−0.05	−2.05	[−0.11, 0.001]

$*p < 0.05$; $**p < 0.005$.
Note: Data presented as *M* ± *SD*. BMI = body mass index; CI = confidence interval; FEV_1 = forced expiratory volume in 1 s; FVC = forced vital capacity; PEF = peak expiratory flow.

including asthma, wheezing, running noses, chronic cough, dyspnea and chronic bronchitis in workers exposed to flour dust were significantly higher than in controls. Another study showed that even exposure to a relatively low concentration of inhalable flour dust puts workers at risk of developing pulmonary symptoms and severe respiratory tract responses [26].

The results of this study showed that pulmonary indices, including FVC, FEV_1 and PEF, significantly decreased after 2 years. The decrease in the FVC index was more than in the FEV_1 index, and this led to an increased FEV_1/FVC index. Since the pattern of restrictive lung disease is associated with reduced FVC, FEV_1 and PEF values and increased FEV_1/FVC, the results of this study suggest that exposure to flour dust increases the likelihood of developing restrictive pulmonary disease. However, there is still debate about the relation between flour dust exposure and the type (obstructive and restrictive) of pulmonary disease. Similar to the present study, Meo and Al-Drees [16] showed that exposure to wheat flour dust in mill workers was related to a significant decrease in the overall mean values of FCV, FEV_1, PEF and maximum voluntary ventilation. Their results suggested that exposure to flour dust causes a restrictive pattern as well [16]. Similar to our observations, bakery staff had a lower level of FVC and FEV_1 compared to the control group in the study by Zai and Khaliq [27], while the FEV_1/FVC ratio did not differ significantly between the two groups. They also concluded that exposure to flour dust could lead to restrictive lung disease. However, some studies have reported that the FEV_1/FVC ratio in the exposure group was significantly lower than in the control group, and suggested that the risk of obstructive pulmonary disease increases [2,15,25]. In addition, Wagh et al. [17] showed that a large number of flour mill workers suffer from both restrictive and obstructive respiratory diseases. These different results can be due to differences in study design, the flour dust composition and the intensity of exposure.

Most studies conducted on the relation between exposure to flour dust and pulmonary parameters were cross-sectional or case–control and few cohorts have been published up to now. A cohort study conducted on 300 newly employed workers with no previous occupational exposure to flour dust showed that the incidence rate of eye/nose symptoms (itching in the eyes and nose, sneezing and runny nose) and chest symptoms (shortness of breath, difficulty in breathing and wheezing) were high at 11.8 and 4.11/100 people in a year, respectively. A significant relation was found between the risk of developing pulmonary symptoms and the estimated amount of exposure to flour dust as well [28].

Pulmonary problems caused by flour dust can occur not only due to the proteins and the main components of flour, but also due to dough improvers such as enzymes, chemical compounds, condiments, spices and other additives. In addition to these, other compounds such as insecticides, pesticides, germs and mites may be present in flour dust. Hypersensitivity pneumonitis, also known as extrinsic allergic alveolitis, is one of the restrictive pulmonary disorders, first diagnosed by Bernardo Ramazzini in wheat harvesters in 1713. This pneumonia is caused by immunological induced inflammation of the lung parenchyma in response to inhalation of a large variety of antigens [29]. Gerfaud-Valentin et al. [30] reported a 30-year-old woman who had worked in a bakery for only 8 months and was exposed to wheat and barley flour dust for 11 h /day and showed manifestations of hypersensitivity pneumonitis. The reason for these symptoms was probably the presence of impurities in flour, including *Aspergillus fumigatus* and *Acarus siro* flour mites. Her symptoms improved significantly after avoiding this occupational exposure [30]. In another study, exposure to flour yeast had been reported as the cause of developing hypersensitivity pneumonitis in a dairy farmer [31]. In a case report by Sundaram et al. [24], two people who worked with poor ventilation at a wheat flour mill which used silica-containing rocks for grinding had developed hybrid dust fibrous, pneumoconiosis associated with a restrictive pattern and intra-network change in high-resolution computed tomography. The term ‘flour mill lung’ was proposed for this form of pneumoconiosis [24]. Silica exposure itself is a major factor related to chronic lung disease [32].

According to the linear regression results, age, obesity, smoking and exposure to respirable flour dust were the predictors of FVC, FEV_1 and PEF. Smoking and increased work experience were other predictive variables of FVC and PEF, respectively. It seems that the main reason why smoking was not a significant predictor for all spirometry indices is that we questioned smoking only by a yes/no question, while we did not measure the intensity of smoking that is a very important parameter in the negative effects of smoking on these indices. In a study conducted by Said et al. [1] on 30 bakers, the only significant relation was found between age and the FVC index, while FEV_1 and FEV_1/FVC did not correlate with age. In addition, they found a significant relation between work experience and smoking with the FEV_1 and FEV_1/FVC indices, which was not found in the present study [1]. Differences in the sample size and age groups could be the reason for these different results.

The relation between age increase and reduced FVC, FEV_1 and PEF has been shown among healthy people as well. However, there was no significant relation between age and changes in FEV_1/FVC [33,34]. This suggests that aging, even without exposure to harmful dust, can still reduce pulmonary function.

The relation between smoking and reduction of pulmonary indices (FVC, FEV_1, FEV_1/FVC and forced expiratory flow (FEF)) was illustrated in a study by Mohammadien et al. [2], which shows that smoking can cause harmful effects on pulmonary function, with the two main mechanisms being oxidative stress damage and protease–antiprotease imbalance [35].

The effect of the body mass index (BMI) on pulmonary parameters (FVC, FEV_1 and PEF) has been shown in previous studies [36,37]. Helala et al. [38] showed that the BMI can reversely affect the FVC and FEV_1 indices in people with chronic obstructive pulmonary disease (COPD) [38]. In normal breathing, the diaphragm contracts and moves the abdominal contents up and down. At the same time, the contraction of the transcostal muscles takes the ribs up and down. However, in obese people, excessive fat covering the thorax and abdomen prevents proper movement of the respiratory muscles [39].

Some studies have reported a significant relation between the amount of exposure to dust flour and a reduction in all pulmonary indices (FVC, FEV%, FEV_1/FVC, FEF25% and FEF75%) [2,25]. Macrophages and the mucociliary system are responsible for clearing flour particles from the lungs. However, high exposure may reduce the ability of macrophages to clear the particles, which will result in the penetration of dust particles into the interstitium. Although these particles are generally cleared by the mucociliary mechanism, this process may be prolonged if the airways are damaged by smoking or inhalation of fumes.

5. Conclusion

The present study showed that most workers in flour mills are exposed to flour dust more than the threshold limit value which has been proposed by the ACGIH, and this might reduce their pulmonary function and lead to pulmonary symptoms in the long term. The most important predictor variables for pulmonary indexes were age, BMI, smoking and the amount of exposure to respirable dust. These findings show that control measures should be implemented in mills and bakeries. Finally, it is recommended to examine workers of mills and bakeries before recruiting and periodically during employment to identify vulnerable people, susceptible to pulmonary events, so that effective measures can be adopted to minimize exposure. In addition, some other measures such as using some production processes which minimize flour dust generation, local and general ventilations, and teaching proper working behaviors can be taken to mitigate exposure to flour dust.

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