Prevalence of respiratory disorders among primary aluminum workers, and their relation to the duration of exposure and smoking habits

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Introduction and study methods
A cross-sectional study was conducted to describe the pattern of respiratory disorders and some associated risk factors among 260 aluminum-exposed workers and 80 nonexposed workers. Data were collected by a respiratory symptoms questionnaire. Spirometry and chest radiography were performed on all participants.

Results
The aluminum-exposed workers suffered significantly more from chronic cough, phlegm, wheezes and breathlessness (34.2, 42.3, 42.3 and 36.9%, respectively) compared with nonexposed workers ($P < 0.05$). Mean values of spirometric measurements regarding FVC%, FEV1%, FEV1/FVC and PEF25–75% as percentages of predicted were significantly lower among exposed workers (84.15 ± 15.02, 88.77 ± 17.65, 106.15 ± 14.72 and 81.34 ± 29.1, respectively) compared with nonexposed workers ($P < 0.05$).The interpretation of chest radiographies revealed that abnormal chest rdaiographies were significantly more predominant in exposed workers than in the nonexposed group ($P < 0.05$). There was a significantly higher occurrence of asthma among exposed workers (8.1%) compared with nonexposed workers (1.2%), with P value 0.03. The prevalence of respiratory symptoms, abnormal ventilatory function measurements and abnormal radiographies were higher among the exposed workers who were smokers and in those with duration of exposure of more than 25 years.

Conclusion
The occurrence of respiratory symptoms, airway diseases, ventilatory function abnormalities and abnormal rdaiographies were higher among the exposed workers, especially those who were smokers and had a duration of exposure of more than 25 years. For prevention of these hazards, general and personal measurements must be performed, for example, engineering, personal protective equipments and more medical care for workers (pre-employment and periodic medical examinations).

Keywords:
asthma, primary aluminum industry, pulmonary infiltration, respiratory disorders

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Introduction

Aluminum (Al) is the most abundant metal and the third most abundant element, after oxygen and silicon, in the earth's crust (8%). Because aluminum is a very reactive element, it is never found as free metal in nature. It is found in combination with other elements, most commonly with oxygen, silicon and fluorine [1]. No known useful biological function was identified for aluminum. Aluminum is now being implicated as interfering with a variety of cellular and metabolic processes in the nervous system and in other tissues [2].

Workers at aluminum production industry are exposed to various occupational hazardous factors such as fumes and gases (mainly hydrogen fluoride), mineral dusts, coal tar pitch volatiles, electromagnetic fields, heat and others [3].

Occupational asthma is the principal respiratory health problem within the primary aluminum industry, with improvement of the physical symptoms and signs after cessation of exposure or merely changing the jobs of affected workers [4]. It is known that not only asthma but a much wider range of lung diseases may be caused by occupational factors in aluminum production: toxic dust chronic bronchitis, chronic obstructive pulmonary disease (COPD), alveolitis, pneumosclerosis, pneumoconiosis and oncological respiratory diseases [5].

The aim of this work was to describe the pattern of respiratory disorders and some of associated risk factors among workers engaged in the primary aluminum industry in comparison with the nonexposed group.

Participants and methods

A cross-sectional study was conducted in an aluminum factory in Egypt. The sample size was calculated using EPI info 2000 statistical package. The calculated sample size was 340 workers (Atlanta, Georgia, USA). This study was based on a stratified random sample of the workers in the factory. The studied workers were classified into two groups according to their exposure; group 1:260 exposed workers randomly selected from pot rooms and cast house sectors, who were exposed to hazardous effects of the primary aluminum industry for 8 h/day; group 2: 80 nonexposed workers randomly selected from administrative, financial and commercial sectors, who were working in places far away from the production sectors so they were not exposed to the industrial hazards.

Data collection was carried out from January 2015 to September 2015. The aim of the study was explained to the workers and informed consent was obtained from them. Data were collected from the workers under the study by a semistructured questionnaire, where data about chronic respiratory symptoms such as chronic cough/phlegm, dyspnea and recurrent chest wheezes were collected [21]; moreover, it included questions suggesting acute work-related symptoms such as cough, chest tightness, nasal irritation, throat irritation and sneezing on exposure to work environment. In addition to respiratory symptoms, the questionnaire contained questions about personal data, pattern of exposure to pollutants, either continuous, intermittent or no exposure and smoking history.

Details about the occupational history of the present occupation (duration of exposure in years, working days/week, shift duration in hours and type of exposure) and previous jobs were obtained.

Ventilatory function tests were carried out for all studied workers at their work sites by a trained medical technician using a calibrated portable spirometer [which included forced vital capacity (FVC), forced expiratory volume in the first second (FEV1), forced expiratory volume in the first second as a percentage of the forced vital capacity (FEV1/FVC%) and forced midexpiratory flow rate (PEF25–75%). The spirometry results were represented as percentages of predicted normal values. A posteroanterior chest radiographic film at deep inspiration was taken for each participant of the studied workers.

Statistical analysis

Analysis of data was performed using Statistical Package for the Social Sciences program, version 16. Statistical methods were applied including descriptive statistics (mean, SD, frequency distribution and cross tabulation), significance tests (*t*-test for quantitative data and χ^2 for categorical data) and correlation. *P* value was considered significant when it was less than 0.05.

Results

Table 1 shows some demographic characteristics and smoking habits of exposed and nonexposed workers. There is no statistical significant difference ($P > 0.05$) concerning age, duration of employment, residence and smoking habit.

Table 2 shows that the aluminum-exposed workers suffered significantly more from chronic cough, phlegm, wheezes and breathlessness (34.2, 42.3, 42.3 and 36.9%, respectively) compared with nonexposed workers (17.5, 17.5, 23.8 and 25%, respectively) ($P < 0.05$).

Table 3 shows that mean values of spirometric measurements regarding FVC%, FEV1%, FEV1/FVC and PEF25–75% as percentages of predicted were significantly lower among exposed workers (84.15 ± 15.02, 88.77 ± 17.65, 106.15 ± 14.72 and 81.34 ± 29.1, respectively) compared with nonexposed

Table 1 Demographic characteristics of the study participants from a primary aluminum industry, 2015

General characteristics	Exposed workers (260)	Nonexposed workers (80)	*P*
Age (years) (mean±SD)	49.63±8.58	47.39±10.24	0.06[a]
Duration of current work (years) (mean±SD)	25.68±9.72	23.92±10.79	0.17[a]
Residence (*n* (%))			
Urban	111 (42.7)	42 (52.5)	0.12[b]
Rural	149 (57.3)	38 (47.5)	
Smoking habits (*n* (%))			
Smokers	123 (47.3)	40 (50)	0.42[b]
Ex-smokers	39 (15.0)	8 (10)	
Nonsmokers	98 (37.7)	32 (40)	

[a]Independent sample *t*-test. [b]Pearson χ-test.

Table 2 Chronic respiratory symptoms among the study participants from a primary aluminum industry, 2015

Chronic respiratory symptoms	Exposed workers (260) (*n* (%))	Nonexposed workers (80) (*n* (%))	*P*
Cough	89 (34.2)	14 (17.5)	0.004*
Phlegm	110 (42.3)	14 (17.5)	0.000*
Wheezes	110 (42.3)	19 (23.8)	0.003*
Breathlessness	96 (36.9)	20 (25.0)	0.049*
Chest pain	50 (19.2)	11 (13.8)	0.264

*Significant values and Pearson χ^2-test.

workers (93.35 ± 12.58, 99.16 ± 13.31, 112.78 ± 11.36 and 92.59 ± 26.01, respectively) ($P < 0.05$). It also shows the interpretation of chest radiographs and reveals that reticular (17.3% of exposed group) and reticulonodular infiltrations (7.3%) patterns were significantly more predominant in exposed workers than in the nonexposed group ($P < 0.05$).

Fig. 1 shows that there was a significantly higher occurrence of asthma among exposed workers (8.1%) compared with nonexposed workers (1.2%), with *P* value 0.03, whereas no significant difference was observed with regard to the occurrence of COPD in the studied groups ($P = 0.34$).

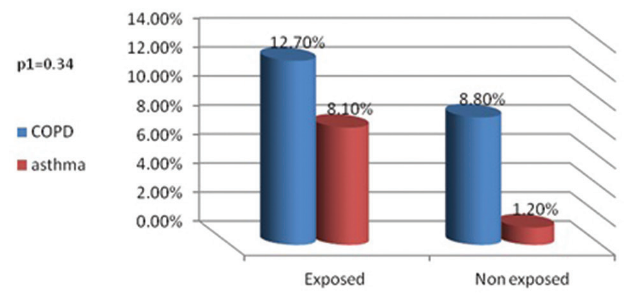
Table 3 Ventilatory function parameters and chest radiographic findings among the study participants from a primary aluminum industry, 2015

Investigations	Exposed workers (260)	Nonexposed workers (80)	P
Ventilatory function parameters (mean±SD)			
FVC%, predicted	84.15±15.019	93.35±12.577	0.000*
FEV1%, predited	88.77±17.652	99.16±13.310	0.000*
FEV1/FVC%	106.15±14.726	112.78±11.358	0.000*
PEF25-75%	81.34±29.100	92.59±26.014	0.002*
Chest radiographic findings (*n* (%))			
No lung infiltration	192 (73.8)	75 (93.8)	
Reticular infiltration	45 (17.3)	3 (3.8)	0.003**
Nodular infiltration	4 (1.5)	0 (0)	
Reticulonodular infiltration	19 (7.3)	2 (2.5)	

FEV1, forced expiratory volume in the first second; FVC, forced vital capacity; PEF25-75%, forced midexpiratory flow rate
*Significant values and independent sample *t*-test. **Significant values and fisher exact test.

Table 4 shows the occurrence of acute work-related respiratory symptoms among the exposed workers in relation to their smoking habit; it revealed that the occurrence of acute work-related nasal irritation, sneezing, throat irritation and cough among the exposed group were higher among smokers (32.5, 30.9, 24.4 and 15.4%, respectively), but the difference between the three groups was statistically insignificant ($P > 0.05$). The mean values of spirometric measurements (FVC%, FEV1%, FEV1/FVC and PEF25–75%) in the exposed workers were lower in smokers (83.28 ± 13.43, 87.68 ± 16.66, 105.67 ± 15.89 and 79.79 ± 29.34, respectively) and ex-smokers (81.08 ± 14.01, 85.64 ± 16.31, 105.69 ± 14.41 and 79.67 ± 27.23) than in nonsmokers, but the difference between the three groups was statistically insignificant ($P > 0.05$). It also shows the chest radiographic findings of the exposed group in relation to their smoking habit and shows that higher percentage of normal radiographs among nonsmokers (69.1% of the chest radiographs

Figure 1



Occurrence of airway diseases among the study participants, primary aluminium industry, 2015. *Significant values and Pearson's χ^2-test.

Table 4 Distribution of respiratory symptoms, ventilatory function parameters and chest radiographic findings among the exposed individuals according to their smoking habit (primary aluminum industry, 2015)

	Smoking habit			P
	Smokers (123)	Ex-smokers (39)	Nonsmokers (98)	
Acute symptoms (*n* (%))				
Cough	19 (15.4)	5 (12.8)	13 (13.3)[b]	0.866
Chest tightness	22 (17.9)	8 (20.5)	9 (9.2)[b]	0.115
Nasal irritation	40 (32.5)	9 (23.1)	26 (26.5)[b]	0.428
Throat irritation	30 (24.4)	7 (17.9)	21 (21.4)[b]	0.677
Sneezing	38 (30.9)	11 (28.2)	28 (28.6)[b]	0.912
Ventilatory function parameters (mean±SD)				
FVC%, predicted	83.28±13.434	81.08±14.014	86.47±16.976[c]	0.111
FEV1%, predicted	87.68±16.664	85.64±16.314	91.38±19.135[c]	0.147
FEV1/FVC%	105.67±15.889	105.69±14.412	106.93±13.384[c]	0.802
PEF25-75%	79.79±29.338	79.67±27.227	83.96±29.615[c]	0.531
Chest radiographic findings (*n* (%))				
No lung infiltration	85 (69.1)	30 (76.9)	77 (78.6)[a]	
Reticular infiltration	24 (19.5)	8 (20.5)	13 (13.3)[a]	
Nodular infiltration	3 (2.4)	0 (0)	1 (1.0)[a]	0.506
Reticulonodular infiltration	11 (8.9)	1 (2.6)	7 (7.1[a]	

FEV1, forced expiratory volume in the first second; FVC, forced vital capacity; PEF25-75%, forced midexpiratory flow rate. NB: significance take symbol (*) and type of test take another symbol (a, b, c). *Significant [a]fisher exact test, [b]pearson chi square, [c]one-way ANOVA test.
*Significant values and Pearson χ^2-test.

of the smokers, 76.9% of ex-smokers and 78.6% of nonsmokers were normal regarding the lung infiltration), but also without a statistically significant difference between different groups ($P > 0.05$).

Table 5 shows the occurrence of acute work-related respiratory symptoms among exposed workers in relation to the duration of exposure in years to aluminum emissions and it revealed that chest tightness was significantly more frequent among workers who were exposed to aluminum emissions for more than 25 years (19.1%) than those with a duration of exposure of 25 years or less (9.3%) ($P = 0.02$). It also shows that the distribution of abnormal ventilatory function measurements regarding FVC%, FEV1% and PEF25–75% were significantly higher among workers who were exposed to aluminum emissions for more than 25 years (43.4, 34.2 and 57.9%) than those with a duration of exposure 25 years or less (25.9, 14.8 and 36.1%) ($P < 0.05$). It also shows the findings of chest radiographs of the exposed group in relation to their work duration in years and that a higher percentage of abnormal radiographs were detected among the exposed workers with work duration of more than 25 years, especially reticular and reticulonodular infiltration patterns, but without a statistically significant difference between the two groups ($P > 0.05$).

Discussion

Aluminum, the most abundant metal on earth, is found in soil, water and air. Its chemical and physical properties make it ideal for a wide variety of uses; for example, aluminum and its compounds are often used in food as additives, in drugs (e.g., antacids), in consumer products (e.g., cooking utensils and aluminum foil) and in the treatment of drinking water (e.g., coagulants) [6]. Occupational exposure to aluminum occurs during the refining of the primary metal and in secondary industries that use aluminum products.

It had been reported that the aluminum industry had adverse respiratory tract effects. Asthma-like symptoms, known as pot room asthma, have been the most intensely investigated respiratory effects. Wheezing, dyspnea and impaired lung ventilation (typically assessed by measuring FEV1 and FVC) are the primary findings of this disorder. Studies on the etiology of pot room asthma in the primary aluminum industry suggested that exposure to fluorides may be an important determinant. The respiratory problems documented in pot room aluminum workers are generally associated with toxic chemicals other than aluminum in the workplace [7].

In this study, there was no statistical significant difference between the exposed and nonexposed workers with regard to age, duration of work, smoking habits and residence (Table 1).

In our study, aluminum-exposed workers suffered significantly more from chronic cough (34.2%), phlegm (42.3%), wheezes (42.3%) and breathlessness (36.9%) than nonexposed workers.

This may be due to inhalation of irritant pollutants, especially fluorides, dust and fumes, in

Table 5 Distribution of acute work-related symptoms, ventilatory function parameters and chest radiographic findings among the exposed individuals according to their duration of exposure in years (primary aluminum industry, 2015)

	Work duration in years (*n* (%))		*P*
	Work duration ≤25 years (108)	Work duration >25 years (152)	
Acute symptoms			
Cough	12 (11.1)	25 (16.4)	0.2[b]
Chest tightness	10 (9.3)	29 (19.1)	0.02[b]
Nasal irritation	33 (30.6)	42 (27.6)	0.6[b]
Throat irritation	21 (19.4)	37 (24.3)	0.4[b]
Sneezing	32 (29.6)	45 (29.6)	0.9[b]
Ventilatory function parameters			
FVC%, predicted (<80%)	28 (25.9)	66 (43.4)	0.004[b]
FEV1%, predicted (<80%)	16 (14.8)	52 (34.2)	0.000[b]
FEV1/FVC% (<75%)	1 (0.9)	4 (2.6)	0.3[a]
FEV1/FVC% (<75%)	39 (36.1)	88 (57.9)	0.001[b]
Chest rdaiographic findings			
No lung infiltration	83 (76.9)	109 (71.7)	
Reticular infiltration	16 (14.8)	29 (19.1)	0.758[b]
Nodular infiltration	2 (1.9)	2 (1.3)	
Reticulonodular infiltration	7 (6.5)	12 (7.9)	

FEV1, forced expiratory volume in the first second; FVC, forced vital capacity; PEF25-75%, forced midexpiratory flow rate. NB: significance take symbol (*) and type of test take another symbol (a, b). *Significant values and Pearson χ^2-test. **Significant values and Fisher exact test. [a]Fisher exact test, [b]Stand for pearson chi square.

aluminum-producing facilities [8]. Barnard *et al.* [9] reported that work-related upper respiratory tract irritation and chronic respiratory symptoms among a group of workers in Australian smelters were attributed to mucosal irritation and reflex bronchoconstriction resulting from inhaled aluminum fumes and/or dust [9]. Our results were, however, in contrast to those of Chan-Yeung *et al.*, [10] who conducted a 6-year follow-up study that included workers in an aluminum smelter in British Columbia and found that there was no statistically significant difference between workers in aluminum smelter and the controls with regard to respiratory symptoms; they attributed their results to a 'healthy worker' program and improvement in the working condition of the smelter [10].

We found that the exposed workers showed significantly lower mean values of FVC, FEV1, FEV1/FVC and PEF25–75% compared with nonexposed workers as shown in Table 3. Abramson *et al.* [11] said that aluminum workers are exposed to different air contaminants that are irritants and may be responsible for respiratory disorders and spirometric measurement changes [11].

Our results were consistent with those of Chan-Yeung *et al.* [12], who investigated 495 Canadian workers who spent more than 50% of their working time in the pot room and found that cough and wheeze were more prevalent and FEV1, and PEF25–75% were decreased compared with a group of nonpot-room workers [12]. Another study had not found a significant impairment in lung function among aluminum pot room workers [13]. There is some evidence that negative findings could be due to a healthy worker behavior [10].

Interpretation of chest radiographs revealed that reticular and reticulonodular infiltrations patterns were significantly more predominant in exposed workers compared with nonexposed workers also as stated in Table 3. This is may be due to exposure to aluminum oxide, which may cause aluminosis or so-called aluminum pneumoconiosis [14].

On studying the prevalence of airway diseases in the studied groups, it was revealed that there was no significant difference with regard to the occurrence of COPD in the studied groups as shown in Fig. 1. COPD could be diagnosed by the occurrence of frequent cough with some phlegm, shortness of breath, often wheezes and impaired ventilatory functions; it is most commonly due to tobacco smoking [15]. In our study, it was found that the studied workers had a similar risk of smoking as shown in Table 1 and it may be the cause that there was no significant difference between different groups in the occurrence of COPD. However, with regard to asthma, there was a significantly higher occurrence of asthma among exposed workers (8.1%) as shown in Fig. 1. This also is in accordance with a study conducted by Cvejanov Kezunović [16] on 215 pot room workers from the aluminium factory in Podgorica, Montenegro; he found that pot room workers mostly complained of breathlessness associated with the workplace (56.7%) or weather changes (rain, cold, wind and humidity) (41.9%) and of dyspnea when climbing stairs (51.2%), but only 22.3% reported using medication to treat these episodes[16].

Also, in the current study, among aluminum-exposed workers, the prevalence rates of most acute work-related symptoms were higher among smokers than among nonsmokers as shown in Table 4, but the differences were statistically insignificant.

It also showed that mean values of spirometric measurements (FVC%, FEV1%, FEV1/FVC and PEF25–75%) in the exposed workers were lower among smokers than among nonsmokers, but with no statistically significant difference between different groups. Also, Table 4 reveals that a higher percentage of abnormal chest radiographs were present in the smokers group, but without a statistically significant difference between different groups ($P > 0.05$). Our findings matched those of Martin *et al.* [17] and Radon *et al.* [18], who revealed an absence of combined effects of smoking and occupational exposure to aluminum on the respiratory health of aluminum-exposed workers [17,18]. However, our results were in contrast to those of Clonfero *et al.* [19], who reported that respiratory adverse effects among aluminum-exposed workers were greater among exposed smokers. The investigators raised the possibility of a synergistic effect of exposure and smoking [19].

In the present study, the prevalence rates of acute work-related symptoms were higher among aluminum-exposed workers with a duration of occupational exposure of more than 25 years as shown in Table 5; the differences were statistically significant only for breathlessness. Also, it was found that there were abnormal ventilatory function measurements among those exposed to aluminum industry emission (>25 years). The present study revealed that the radiological findings more predominant among workers who had been exposed to aluminum industry emissions for more than 25 years. This may be due to the cumulative effect of exposure to aluminum industry emissions; this means that the duration of exposure plays an important role in progression of health hazards of the respiratory tract. Our results matched with those obtained by Kongerud *et al.* [20], who found that odd ratio of airflow limitation increased with increasing duration of employment [20].

Also, our results are in accordance with those of Chan-Yeung *et al.* [10], who mentioned that older workers in aluminum smelters had a greater decline in lung function compared with younger workers [10].

Conclusion and recommendations

The occurrence of respiratory symptoms, airway diseases, ventilatory function abnormalities and abnormal radiographs were significantly higher among the workers in aluminum industry, especially those with a duration of exposure of more than 25 years. General and personal measurements must be performed for prevention of these hazards, for example, engineering, personal protective equipments and more medical care for workers (pre-employment and periodic medical examinations); these examinations should include pulmonary function tests and chest radiography.

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Conflicts of interest

There are no conflicts of interest.

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