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Respiratory pathology pattern of aluminium industry workers in Russian Arctic

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Abstract. The aim of the study is to investigate risks, prevalence, clinical forms of chronic bronchopulmonary diseases (CBPD) in aluminum workers and assess whether asthma and other respiratory conditions occur excessively among pot workers. The survey of 479 workers at Kandalaksha aluminum smelter has shown that the most prevalent respiratory disease is chronic bronchitis (CB) detected in 13,4-17,0 % of workers. Chronic obstructive pulmonary disease (COPD) and asthma (all forms) are diagnosed much less frequently (2,9 % each). The development of CB and COPD is closely associated with the degree of exposure to tobacco smoke and harmful production factors. Work experience lasting 6-14 years has led to an increased risk of CB / COPD to 5,11 (CI 1,26-20,80), work experience lasting for more than 14 years – up to 7,78 (CI 1,93-31,33) as compared with the employment duration of less than 6 years. CB/COPD are diagnosed in 31,3 % of smokers and only in 5,8 % of non-smokers ($p < 0,01$). In case of asthma, such a link is missing. Potroom asthma should be highlighted among the various pathogenetic variants of the disease identified in the aluminum industry workers. This variant of asthma with currently unclear causal factors and features of the pathogenesis is a specific health disorder to a given occupational group. The prevalence of CB, COPD and asthma (all forms) do not differ significantly among workers employed directly in servicing the electrolysers, and workers in other parts of the production of aluminum. The only exception is potroom asthma that develops more frequently in the exposed group of pot and anode operators. It has been concluded that the medical and social significance of potroom asthma requires further investigation of the unknown features of etiology and pathogenesis of this disease.

Аннотация. Исследованы факторы риска, распространенности и клинических форм хронических бронхолегочных заболеваний (ХБЛЗ) у работников алюминиевой промышленности, а также особенности развития ХБЛЗ и астмы у работников, непосредственно обеспечивающих функционирование электролизеров. Анализ состояния здоровья 479 работников Кандалакшского алюминиевого завода показал, что наиболее распространенным респираторным заболеванием является хронический бронхит (ХБ), выявляемый у 13-17,4 % рабочих. Значительно реже диагностировались хроническая обструктивная болезнь легких (ХОБЛ) и астма (все формы) – по 2.9 %. Развитие ХБ и ХОБЛ оказалось тесно связанным со степенью экспозиции к табачному дыму и вредным производственным факторам. Стаж работы продолжительностью 6-14 лет приводил к увеличению риска развития ХБ/ХОБЛ до 5,11 (CI 1,26-20,80), а более 14 лет – до 7,78 (CI 1,93-31,33) по сравнению с длительностью работы менее 6 лет. ХБ / ХОБЛ были диагностированы у 31,3 % курящих работников и только у 5,8 % некурящих лиц ($p < 0,01$). В отличие от ХБ / ХОБЛ связь развития астмы с курением и продолжительностью воздействия вредных производственных факторов не выявлялась. Среди патогенетических вариантов астмы, выявляемых у работников алюминиевой промышленности, следует выделить "potroom" астму. Этот вариант астмы с невыясненными в настоящее время причинными факторами и особенностями патогенеза является специфическим заболеванием для данной профессиональной группы. Показатели распространенности ХБ, ХОБЛ и БА (все формы) существенно не отличаются у работников, занятых непосредственно обслуживанием электролизеров, и работников других участков производства алюминия. Только "potroom" астма развивается чаще у более экспонированной группы электролизников и анодчиков (2,9 % работников). Сделан вывод о том, что медико-социальная значимость "potroom" астмы обусловливает необходимость дальнейшего изучения неясных вопросов этиопатогенеза данного заболевания.

Key words: aluminium production workers, bronchopulmonary diseases, potroom asthma
Ключевые слова: работники алюминиевой промышленности, бронхолегочные заболевания, астма

1. Introduction

Workers at aluminium smelters are exposed to various occupational hazardous factors such as fumes and gases (mainly hydrogen fluoride), mineral dusts, coal tar pitch volatiles, electromagnetic fields and others (*Radon et al*., 1999; *Kongerud*, 2007). It has been shown that potroom work may result in long-term lung function impairment and in an asthma-like syndrome of unknown pathogenesis. It is termed "potroom asthma"

and is more common for workers engaged directly in serving pots (*Kongerud et al*., 1994; *O'Donnell*, 1995; *Sjaheim*, 2007). However, it is known that not only asthma but a much wider range of lung diseases may be caused by occupational factors in aluminium production: toxic dust chronic bronchitis (CB), chronic obstructive pulmonary disease (COPD), alveolitis, pneumosclerosis, pneumoconiosis, oncological respiratory diseases (*Mileshnikova*, 2003; *Roslyi*, 2003).

The aim of the study was to investigate risks, prevalence, clinical forms of chronic bronchopulmonary diseases (CBPD) in aluminium workers and assess whether asthma and other respiratory conditions occur excessively among pot workers.

2. Material and methods

The cross-sectional clinical and epidemiological study involved 479 male workers at the Kandalaksha aluminium smelter (KAS) located in the Murmansk region, Russia. The first group consisted of 277 pot workers (cell and anode operators). The second group was formed by 202 non-pot workers engaged in other aspects of aluminium manufacturing and who were not directly exposed to chemical and physical hazards arising from the operation of pots (crane operators, loaders, fitters, electricians, and other maintenance employees).

Before being allowed to work at the KAS all job seekers underwent pre-employment medical examination to screen out those with current respiratory problems, childhood or family asthma and/or bronchitis history. Subsequently they underwent annual medical check-ups including an interview (a questionnaire on demographic data, smoking and drinking habits, daily physical activity, previous and current respiratory symptoms), examination by a chest physician, spirometry, chest X-ray, electrocardiogram, routine blood and urine analyses. Lung function tests ("Microlab 3500 v 5.0", "Micro Medical Ltd", England) included determination of forced expiratory volume in the first second (FEV_1), vital capacity (VC), forced VC (FVC), FEV_1/FVC ratio, peak expiratory flow (PEF), maximal expiratory flow at 75 %, 50 % and 25 % levels of FVC (MEF_{75}, MEF_{50}, MEF_{25}) and bronchodilator reversibility testing with 400 mcg of salbutamol. Measurements were electronically converted to BTPS (body temperature and pressure saturated) conditions. Spirometry results were given as percentages of predicted normal values. The point (pt) system was used for objective assessment of clinical symptoms: 1 pt – clinical symptom is absent, 2 pts – clinical symptom is present, 3 pts – severe clinical symptom is present. Chronic bronchitis (CB), chronic obstructive pulmonary disease and asthma were diagnosed in accordance with internationally accepted criteria (*Global initiative for asthma*, 2009; *Global initiative for chronic…*, 2009). We used term "at risk group" for patients with some mild clinical and/or functional signs of respiratory pathology which were not sufficient for diagnosing any nosological form of bronchopulmonary pathology. Assessment of working conditions was based on the results of regular certification of workplaces. Cumulative tobacco smoke exposure (TSE) was calculated in "pack-year" units (*Buist et al*., 2007). EPI Info, v. 6.04d program (*Epi Info…*, 1994) was applied for statistical analysis of collected data with determination of Student's *t*-criterion and chi-squared (χ^2) criteria, relative risk (RR) and its 95 % confidence interval (CI). We calculated the combined RR for developing CB and COPD (CB/COPD) taking into consideration, on the one hand, that risk factors for both diseases are common. On the other hand, it was impossible to obtain statistically reliable results for COPD due to a small number of COPD cases. All numerical data are given as a mean ± standard error.

3. Results

The electrolysis departments of KAS are equipped with Søderberg type cells. The hygienic assessment of working conditions carried out in the potrooms showed that workers were exposed to a range of air pollutants with their workplace concentrations higher than occupational exposure limits (OEL): hydrogen fluoride, aluminium fluoride, sodium fluoride with cumulative effect exceeding OEL (0,5 mg/m^3) by 1,2-4,4 times, tarry matter including benz(a)pyrene at concentration of 1,5-3,3 mg/m^3 (7,5-16,5 times above OEL of 0,2 mg/m^3), inhalable mineral dusts at concentration of 12,4-184,0 mg/m^3 (3,6-30,6 times above OEL of 6,0 mg/m^3), carbon monoxide at concentration of 43,7-93,7 mg/m^3 (2,2-4,7 times above OEL of 20,0 mg/m^3). The non-pot workers were also exposed to above occupational hazardous factors but their mean concentrations were either within OELs or exceeded the corresponding OELs by not more than 5 times. In the climatic conditions of the Russian North the microclimate of production shops is characterized by great fluctuations of workplace temperatures from –15 °C to +15 °C in the cold season and from +10 °C to +35 °C in the warm season. According to overall estimates (*Guide on Hygienic Assessment…*, 2005), working conditions of cell and anode operators matched hazard classes 3.3-3.4 while those of non-pot workers matched hazard classes 3.1-3.3.

As it is shown in Table 1 mean age of the workers was close to 40 years and mean duration of employment slightly exceeded 10 years. More than half of workers smoked with TSE being above 10 pack/years which is a known risk factor for developing CB/COPD (*Buist et al*., 2007). There were no significant differences in the prevalence of CB, COPD and asthma between the pot and non-pot workers. All 8 moderate asthma cases diagnosed in the first group met potroom asthma criteria (*Abramson et al*., 1989). We observed the following

main manifestations of potroom asthma in our patients: recurrent episodes of wheezing, difficulty in breathing, chest tightness caused by emissions of gases and dust in the potroom atmosphere. Asthma in the second group had different pathogenetic features. Among them, only one case of moderate asthma matched potroom asthma criteria. So prevalence rate of this form of asthma was higher in pot workers than in the comparison group ($p < 0,05$). Another 3 cases of mild intermittent asthma in non-pot workers were caused by hypersensitivity to epidermal allergens and a case of moderate asthma met criteria of physical exertion asthma. The last four cases of disease had nothing to do with the patients' occupation.

Table 1. Demographic and clinical characteristics of aluminium smelter workers

Characteristics	Pot workers (n = 277)	Non-pot workers (n = 202)	P value
Age, years	37,4±0,6	39,1±0,7	>0,1
Duration of employment, years	12,4±0,5	11,5±0,7	>0,2
Prevalence of smoking	163 (58,8 %)	118 (58,4 %)	>0,5
TSE, pack/years	10,7±0,6	11,4±0,8	>0,1
Healthy persons	153 (55,2 %)	119 (58,9 %)	>0,5
At risk group	61 (22,0 %)	50 (24,8 %)	>0,5
CB patients	47 (17,0 %)	27 (13,4 %)	>0,2
COPD patients, %	8 (2,9 %)	2 (1,0 %)	>0,2
Asthma patients, %	8 (2,9 %)	5 (2,5 %)	>0,5

In the compared groups of workers the most common respiratory symptoms were cough (1,35±0,03 and 1,32±0,05 pts, respectively) and expectoration (1,29±0,03 and 1,25±0,03 pts, respectively). The symptoms typical for COPD were diagnosed significantly less frequently: shortness of breath on physical exertion (1,08±0,02 and 1,05±0,02 pts, respectively) and wheezing (1,12±0,02 and 1,08±0,02 pts, respectively). Absence of disease acute onset and gradual slow increase in clinical symptoms were characteristic for patients with CB and COPD in both groups. The main manifestations of potroom asthma were recurrent episodes of wheezing, difficulty in breathing, chest tightness caused by emissions of gases and dust in the potroom atmosphere.

In healthy and "at risk group" persons, as well as in CB and asthma patients all mean values of lung function parameters were within normal range. The decrease below normal values of such indices as FEV_1 (60,2±4,8 %), FEV_1/FVC (59,2±2,5 %), PEF (63,5±4,5 %), MEF_{75} (36,3±3,7 %), MEF_{50} (29,2±4,2 %), MEF_{25} (31,3±3,1 %) was detected only in COPD patients. It is noteworthy that in "at risk group", as compared to healthy persons, we found reduced FEV_1/FVC (80,2±1,0 and 83,1±0,5 %, respectively, $p < 0,05$), PEF (93,3±1,8 and 98,4±1,2 %, respectively, $p < 0,05$), MEF_{75} (91,9±2,9 and 101,5±1,6 %, respectively, $p < 0,05$). This fact may be viewed as early sign of airflow limitation within normal spirometric values. There were no statistically significant differences in clinical symptoms and lung function data between the two groups of workers.

Table 2. Clinical symptoms of bronchopulmonary system disorders (pts) in aluminium smelter workers according to duration of employment (M±m)

Symptoms	Employment duration		
	≤ 5 years n = 108	6-14 years n = 108	≥ 15 years n = 143
Cough	1,14±0,05 1,18±0,06	1,36±0,05[1] 1,33±0,05[1]	1,45±0,05[2] 1,37±0,07
Expectoration	1,12±0,05 1,15±0,05	1,27±0,04[1] 1,26±0,05	1,41±0,05[2, 3] 1,36±0,05[2]
Shortness of breath	1,04±0,01 1,02±0,02	1,13±0,03[1] 1,07±0,02	1,25±0,04[2] 1,18±0,04[2]
Wheezing	1,04±0,02 1,05±0,04	1,16±0,03 1,19±0,03[1]	1,30±0,04[2, 3] 1,26±0,04[2]
Dry râles in the lungs	1,10±0,04 1,12±0,05	1,24±0,04[1] 1,22±0,04	1,38±0,03[2] 1,32±0,05[2]

Note. Upper line – pot workers, lower line – non-pot workers. [1] – employment duration of 5 years versus 6-14 years ($p < 0,05$); [2] – employment duration of 5 years versus 15 years and more ($p < 0,05$); [3] – employment duration 6-14 years versus 15 years and more ($p < 0,05$).

The severity degree of clinical symptoms increased with the prolongation of employment duration (Table 2). Pot workers with tenure of 6-14 years and more than 14 years complained of coughing, brining up phlegm, wheezing at rest, and shortness of breath on physical exertion more frequently than those who worked for less than 6 years ($p < 0,05$). Also, they had higher occurrence of diffuse dry râles in the lungs ($p < 0,05$). In non-pot workers the impact of employment duration on clinical symptoms was less marked but differences between the two groups were insignificant.

In the pot workers group, the prevalence of CB and COPD increased with the increasing period of exposure to industrial hazardous factors. At the same time this trend was accompanied by statistically significant decrease in the number of persons without respiratory symptoms (Table 3). Duration of employment of 6-14 years led to the rise in RR for developing CB/COPD to 5,11 (CI 1,26-20,80; $\chi^2 = 7,21$; $p = 0,0072$) and employment of more than 14 years increased this risk to 7,78 (CI 1,93-31,33; $\chi^2 = 13,94$; $p = 0,0019$) as compared to those who were employed for less than 6 years. In the non-pot workers group the prevalence of CB and COPD as well as the number of healthy persons did not differ statistically with different tenure. As a result there was only a tendency in the rise of RR for developing CB/COPD in workers who were employed for 6-14 years (RR = 1,56; CI 0,54-4,53; $\chi^2 = 0,69$, $p = 0,4062$) and for 14 years and more (RR = 2,40; CI 0,81-7,14; $\chi^2 = 2,69$; $p = 0,1007$) as compared to those who worked for less than 6 years. In contrast to clinical symptoms, there was no close association between lung function parameters and duration of employment. Only decrease in FEV_1/FVC ratio was found in the pot workers being employed for more than 14 years (79,9±0,9 %) and for 6-14 years (80,9±0,7 %) against those who worked for less than 6 years ($p < 0,05$).

Table 3. Prevalence of bronchopulmonary diseases in aluminium smelter workers according to duration of employment

Group	Employment duration		
	≤ 5 years *n* = 108	6-14 years *n* = 228	≥ 15 years *n* = 143
Healthy persons	45 (75,0 %) 35 (72,9 %)	66 (52,8 %)[1] 60 (58,3 %)	42 (45,7 %)[2] 28 (54,9 %)
"At risk group"	10 (16,7 %) 9 (18,8 %)	31 (24,8 %) 27 (26,2 %)	20 (21,7 %) 12 (23,5 %)
CB patients	3 (5,0 %) 4 (8,3 %)	21 (16,8 %)[1] 12 (11,7 %)	23 (25,0 %)[2] 9 (17,6 %)
COPD patients	– –	3 (2,4 %) 1 (1,0 %)	5 (5,4 %) 1 (2,0 %)
Asthma patients	2 (3,3 %) –	4 (3,2 %) 3 (2,9 %)	2 (2,2 %) 1 (2,0 %)

Note. Upper line – pot workers, lower line – non-pot workers. [1] – employment duration of 5 years versus 6-14 years ($p < 0,05$); [2] – employment duration of 5 years versus 15 years and more ($p < 0,05$).

The CB/COPD prevalence was greatly influenced by smoking and the level of TSE. CB/COPD was diagnosed in 31,3 % of smokers and only in 5,8 % of non-smokers ($p < 0,01$) in the pot workers group and in 22,9 % and 2,4 % ($p < 0,01$), respectively in the non-pot workers group. Moreover, in the first group the CB/COPD prevalence in smokers with TSE>10 pack/years increased up to 34,3 % as compared to the CB/COPD prevalence of 21,4 % in smokers with TSE<10 pack/years ($p < 0,05$). In the second group the analogous figures were 30,6 % and 17,4 % ($p < 0,05$), respectively. RR for developing CB/COPD in smoking workers against that in non-smokers was 4,09 (CI 2,02-8,28; $\chi^2 = 20,61$; $p = 0,000006$) in the first and 9,35 (CI 2,29-38,21; $\chi^2 = 16,18$; $p = 0,00006$) in the second group. In both groups RR for developing CB/COPD was still higher in smokers with TSE>10 pack/years versus smokers with TSE<10 pack/years: 1,88 (CI 1,20-2,94; $\chi^2 = 7,17$; $p = 0,0074$) and 4,11 (CI 1,89-8,94; $\chi^2 = 15,71$; $p = 0,00007$), respectively. In contrast to CB and COPD, the prevalence of asthma was not closely associated with duration of employment and smoking status of aluminium smelter workers.

4. Discussion

The study showed that CB is undoubtedly the most widespread (13,4-17,0 %) CBPD among Russian aluminium industry workers. Its prevalence seems higher than 9-16 % reported in various groups of Australian aluminium workers (*Fisher*, 1998) and slightly lower than prevalence of bronchitic symptoms in up to 20 % of carbon bake and potroom employees of a Quebec smelter (*Martin et al.*, 1986). Conversely, only slightly increased prevalence of bronchitic symptoms and COPD was found in aluminium industry workers as compared to general population (*O'Donnel*, 1995). CB is characterized by monotonous long-term cough with scant mucous

phlegm and gradual increase in clinical symptoms. Despite its high prevalence, medical and social significance of CB is limited because it does not greatly restrict professional ability to work. On the contrary, COPD was diagnosed only in 1,0-2,4 % of aluminium workers which was lower than 3-10 % prevalence of COPD at various Norwegian aluminium smelters (*Drabløs*, 1998) and much lower than 28 % in potroom workers that smoked and 19 % of non-exposed workers at three Canadian aluminium smelters (*Martin*, 1998). As a rule, COPD patients experience increasing susceptibility to workplace air irritant agents (less marked than in asthma patients) and progressive intolerance of physical loads which necessitates their transfer to other jobs. In our study prevalence of CB and COPD did not differ significantly between two groups of workers. It supports the earlier made conclusion that work-related respiratory symptoms among aluminium smelter workers do not occur only in potroom employees (*Fritschi et al*., 1999).

Potroom asthma is a subject of special interest for many researchers who worked out its criteria: 1) symptoms comprising difficulty in breathing, chest tightness and/or wheezing, often with cough; 2) a period of initial exposure of 2 weeks or longer before the onset of symptoms occurring for the first time in that individual; 3) symptoms or evidence of airflow obstruction are related in time to exposure; onset of symptoms may occur immediately, after several hours, or during sleep; 4) symptoms improve when the subject is away from work (*Abramson et al*., 1989; *Mapp et al*., 2005).

The number of asthma cases in the studied group of workers was small taking into consideration the reported prevalence of asthma ranging 0-15 % among aluminium industry workers (*Soyseth, Kongerud*, 1992; *Sorgdrager et al*., 1998; *Taiwo et al.*, 2006). But we can not exclude falsely low number of asthma cases due to underreporting of asthmatic symptoms by employees who are afraid of work restrictions and losing their jobs. Workers leaving an industry because of unregistered asthmatic symptoms are likely to create still another confounding factor for assessing real asthma prevalence (*Kongerud et al.*, 1994; *O'Donnel*, 1995).

It is important to differentiate various clinical and pathogenic forms of asthma diagnosed in aluminium smelter workers. Some of them are not work-related being primarily closely associated with pre-existing atopy (as it was in our study). As clinically potroom asthma does not differ from non-occupational asthma, the reliable diagnosis of this condition should be based on detection of industrial causal factors. Among unknown but suspected factors are hydrogen fluoride, sulfur dioxide, dust, trace amounts of metals and others (*Martin*, 1986; *Roslyi*, 2003; *Sjaheim et al*., 2004). As no specific agent in the potroom has been shown, controversy as to whether potroom asthma is pre-existing asthma provoked by pollutants, or asthma that is induced by agents in the work environment will remain (*O'Donnel*, 1995; *Mapp et al*., 2005).

Like other researchers (*Taiwo et al.*, 2006), we found evidence that smoking and length of work do not affect the development of asthma in aluminium industry workers. This fact supports the current understanding of asthma as a disease with predominantly endogenous risk factors (*Global initiative for asthma*, 2009).

It proved extremely difficult to compare the prevalence of CBPD among KAS workers and the local adult population. According to the official statistics in 2007 the average CB, COPD, and asthma prevalence among the adult residents of the town of Kandalaksha were 7,3 ‰, 4,0 ‰ and 5,9 ‰, respectively (*Morbidity in Murmansk…*, 2010) which was 22,1, 5,3 and 4,6 times lower than in the aluminium smelter workers. In all likelihood, the main reason for this discrepancy lies in the application of different diagnostic approaches. On the one hand, it was active detection of early forms of diseases during periodic medical examinations of KAS employees. On the other hand, it was mainly registration of patients seeking treatment and sick-leave certificates at the municipal medical institutions.

It should be noted that potroom asthma, recognized in many countries as an occupational disease (*O'Donnel*, 1995; *Taiwo et al.*, 2006), is not one of them in the Russian Federation (Order of the Ministry of Health № 90 dated March 14, 1996). This prevents as early as possible removal from exposure and onset of rehabilitation measures necessary for the successful treatment of this group of patients (*Mapp et al*., 2005).

5. Conclusion

The prevalence of CB, COPD and bronchial asthma (all forms) do not differ significantly among workers employed directly in servicing pots, and workers in other parts of aluminium production. Unlike all other CBPD, only potroom asthma develops more frequently in the exposed group of pot and anode operators. Medical and social importance of potroom asthma requires further studies of unknown etiological and pathogenetic features of this disease.

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