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Retrospective assessment of occupational disease trends in Russian Arctic apatite miners

Sergei A. Syurin [a], Aleksandr A. Kovshov [a,b], Jon Ø. Odland [c,d] and Lyudmila V. Talykova [a]

[a]Arctic Environmental Health Department, Northwest Public Health Research Center, St. Petersburg, Russia; [b]Department of Hygiene of Educational, Training, Labor Conditions and Radiation Hygiene, Faculty of Preventive Medicine, North-Western State Medical University Named after I.I. Mechnikov, St. Petersburg, Russia; [c]Department of Public Health and Nursing, NTNU Norwegian University of Science and Technology, Trondheim, Norway; [d]Institute of Ecology, HSE University, Moscow, Russia

ABSTRACT

For many years in Russia, apatite ore mining has been associated with high levels of occupational morbidity. The aim of the study was to retrospectively assess occupational disease trends in Russian Arctic apatite miners. We analysed data from routine health screening of 2 649 underground apatite miners in 2007 and data of social-hygienic monitoring “Working conditions and occupational morbidity” in 2008–2020. In 2007, according to the results of routine health screening, 6 778 chronic diseases were diagnosed in 2 649 miners, the most prevalent being musculoskeletal (34.4%) and eye (16.0%) diseases. In the next 13 years, 572 occupational diseases were first diagnosed in 300 (11.3%) miners, most prevalent being musculoskeletal diseases (47.2%). The risk of developing occupational diseases in tunnellers exceeded that in all other miners, including timber-men (RR = 1.56; CI 1.06–2.30), vibration-loading machine operators (RR = 1.67; CI 0.99–2.80), drillers (RR = 1.51; CI 1.08–2.11) and blasters (RR = 2.12; CI 1.55–2.84). We conclude that ongoing modernisation of ore mining processes and medical preventive measures should include more effective health-improving interventions for underground apatite miners. Findings from the analysis of data can be used by health professionals and policy makers to address these problems.

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Introduction

In Russia, apatite-nepheline ores are mined at one of the world’s largest Khibinsky deposit of the Kola Peninsula, located in the western part of the Russian Arctic bordering with Finland and Norway (Figure 1). In the 2000s, the number of employees directly involved in ore mining has averaged 3 000–3 500 people. The apatite concentrate obtained from the ore is used for the production of environmentally friendly phosphorus-containing fertilisers necessary to ensure food security not only in Russia but also in many other countries of the world. The problem of occupational health disorders among apatite miners is not new and can be traced back to the beginning of intensive exploitation of the Khibiny deposits in the 1950s. The emphasis in solving this problem is made on improving working conditions of miners. To achieve this goal, the mechanisation of ore mining processes is constantly being carried out. Also, new mining equipment with improved vibration and noise characteristics, dust suppression systems, as well as modern personal protective equipment are being developed and introduced into practical work [1–3]. However, these measures have a limited effect, as about two-thirds of miners have working conditions that may cause the onset of early stages of occupational diseases. In 2010–2020s, the most important occupational hazards have been heavy physical work, whole-body and hand-arm vibration, noise, chemical factors and low temperatures [4–8].

Along with technical measures, medical methods for maintaining health of miners are being actively developed, including rehabilitation treatment in a specialised health resort. Based on data from routine health screening, the greatest attention is paid to the prevention and treatment of musculoskeletal diseases and vibration disease. Nevertheless, despite all efforts, as before, the apatite miners are included in the group of workers with an increased risk of occupational pathology. On average, 65–70 new cases of occupational diseases are reported in this group of workers annually, which is up to 40–50% of all cases in the region [7,9]. In addition to harmful working conditions, the persistence of high occupational morbidity among

CONTACT Aleksandr A. Kovshov a.kovshov@s-znc.ru Northwest Public Health Research Center, 2-ya Sovetskaya ulitsa, 4, St. Petersburg 191036, Russia; Sergei A. Syurin kola.reslab@mail.ru Northwest Public Health Research Center, 2-ya Sovetskaya ulitsa, 4, St. Petersburg 191036, Russia

Figure 1. Location of Khibiny apatite-nepheline deposits on the Kola Peninsula, Russia (Available at: https://www.maps-of-the-world.ru/europe/russia/large-scale-administrative-divisions-map-of-russia-2009).

miners may be due to the underestimation of developmental risks and insufficient detection of early pathological signs during annual health screening. Also, a negative impact is caused by the lack of a legislative framework for early (before the official diagnosis is approved) transfer of miners with signs of occupational pathology to jobs unrelated to occupational hazards [10].

In Arctic miners, musculoskeletal diseases prevail in the structure of health disorders caused by harmful working conditions [11]. Effects of vibration, noise effects on inner ear, respiratory and nervous diseases are also widespread [12–14]. Besides, climatic conditions of the Arctic were found to have an additional negative effect on the health of mining workers. They overstress the most important functional systems of the body and thus enhance the effect of occupational hazards [15,16]. This combination of unfavourable work-related and climatic factors can result in earlier and more frequent development of occupational diseases [17]. It is known that along with Russia apatite ores are mined in Morocco, South Africa, China, Brazil, Canada and some other countries [18]. However, findings on the association between working conditions on apatite miners´ health, including occupational disease development, are absent in scientific literature.

Increasingly high amount of minerals extracted in Russian Arctic and the need to preserve working population health determine the priority of improving occupational disease prevention in the regional mining industry. The urgency of this task is also emphasised by significant workforce shortage in the Arctic. Findings from the analysis of data can be used by policy makers to address Arctic apatite miners´ health problems.

The aim of the study was to retrospectively assess of occupational disease trends in Russian Arctic apatite miners of various trades.

Materials and methods

According to the Russian legislation, an annual medical examination is mandatory for any person employed in harmful and hazardous working conditions [19]. The initial health assessment of 2 649 underground apatite miners was based on findings of routine health screening carried out in 2007. The analysis included such indicators as age, sex, employment duration, working conditions, nosological forms and classes of non-occupational diseases of the surveyed miners. The above 2 649 workers formed a cohort for a 13-year follow-up study.

We further studied the data of social-hygienic monitoring “Working conditions and occupational morbidity in the Russian Arctic” in 2008–2020 to assess the newly diagnosed cases of occupational diseases and conditions of their occurrence. This information is provided annually by the Russian Federal Service for Surveillance on Consumer Rights Protection and Human Well-being. Socio-hygienic monitoring is the Russian state system for monitoring, analysing, evaluating and predicting the state of public health and life environment. Full access to the data of social-hygienic monitoring is available only to public health professionals; however, part of the information is published annually in state reports on sanitary and epidemiological situation in the country [20].

In Russia, there is the officially approved list of diseases that can be recognised as occupational if a connection is established between their development and exposure to harmful production factors. In workers exposed to harmful working conditions, diseases are considered as non-occupational ones if a causal relationship has not been found between the development of the disease and the action of occupational hazards.

In cases of occupational pathology, an assessment was made of the previous working conditions, the structure and incidence of the identified diseases. We also took into account the age and length of service at the time of disease development with the subsequent determination of the minimum and mean values of these indicators for each professional group. The degree of harmfulness of working conditions was assessed according to the criteria officially adopted in Russia: optimal (class 1), permissible (class 2), harmful (class 3) and extreme (class 4) [21].

Optimal working conditions are those under which the employee health is preserved and prerequisites for maintaining a high performance level are created. Permissible working conditions are characterised by the levels of environmental factors and the labour process indicators which do not exceed the established hygienic standards for workplaces. The level of harmful production factors under harmful working conditions does not meet hygienic standards requirements, resulting in a negative effect on the health of the employee and/or his offspring. Harmful working conditions are divided into 4 degrees of harmfulness. Working conditions of class 3.1 cause functional changes and increase health damage risk. Working conditions of class 3.2 cause persistent functional changes, resulting in development of mild forms of occupational diseases that occur after prolonged exposure (15 or more years). Working conditions of class 3.3 are associated with occupational diseases of mild and moderate severity complicated by decreased or lost working capacity. Working conditions of class 3.4 cause severe forms of occupational diseases often resulting in disability. Extreme working conditions are characterised by the levels of factors, the impact of which within one work shift creates high risk of developing an acute occupational disease or even a threat to life. The algorithm for evaluating the class of working conditions is specified in the Guide on Hygienic Assessment of Factors of Working Environment and Work Load [21].

In addition to harmful production factors and the class of working conditions, we also considered the circumstances in which an occupational disease occurred. The most common of them are imperfection of technological processes and imperfection of workplaces. The first means technical reasons for the occurrence of harmful and hazardous working conditions that cannot be eliminated by observing labour regulations. The second occurs in case of shortcomings that entirely depend on poor organisation of labour at workplaces and at the enterprise as a whole. These include non-observance of labour ergonomics principles, shortcomings in the maintenance of the territory, driveways, passages, violation of storage rules and others.

To analyse the data, Microsoft Excel 2013 software, Epi Info programme (v. 6.04d) and IBM SPSS Statistics (v. 22) were used. We determined the relative risk (RR), the 95% confidence interval (CI) for RR and used the chi-square (χ^2) test to calculate a measure of association. RR was calculated by dividing the probability of an outcome in one group, by the probability of the outcome in another group. CI was determined by using a two-step procedure: CI was generated for Ln(RR), and then the antilogs of the upper and lower limits of CI for Ln(RR) were computed to give the upper and lower limits of CI for the RR [22].

Due to a non-normal distribution in the "Number of diseases", "Age" and "Employment duration" samples (the Kolmogorov-Smirnov test statistics were 0.184, 0.087, 0.151, respectively, $p < 0.001$), the Spearman rank correlation coefficient (ρ) was applied to establish the relationship between the number of diseases, age and work experience. Numerical data are presented as absolute values, percentages, medians with 75th and 25th percentiles (IQR, Q_3 and Q_1) or a mean with the standard error of the mean (M ± SEM). Trends in the number of diseases were estimated by constructing a trend line (polynomial, $n = 2$) and calculating the R-squared value (R^2) to check the accuracy of the approximation. The critical level of significance of the null hypothesis was 0.05.

Results

In 2007, 2 649 employees of underground apatite mines participated in routine annual health screening, which amounted to 98.8% of the personnel (excluding those who were absent for good reason). In accordance with the order of the Ministry of Health of Russia, the diagnostic programme of periodic medical examination depends on the class and nature of exposure to occupational hazards. It includes laboratory tests (blood count, urine test, blood glucose and cholesterol, etc.), functional tests (electrocardiography, spirography, vibration and cold tests, etc.), X-ray of the lungs, examination by a team of specialised doctors. The medical check-up is considered to be completed only if every item of the planned diagnostic programme is fully implemented.

The average age of 2 649 surveyed miners was 39.5 ± 0.2 years (median age was 39 years, IQR = 49–29), and the employment duration in mining was 11.2 ± 0.2 years (median one was 8 years, IQR = 17–4). There were 2 335 (88.1%) males and 314 (11.9%) females among the employees. Those who passed the medical check-up may be allowed to work with certain harmful production factors. Among them were 546 (20.6%) locksmiths (electrical fitters), 223 (8.4%) underground electric locomotive drivers, 190 (7.2%) blasters, 173 (6,5%) underground miners, 158 (6.0%) loader drivers, 150 (5.7%) electric and gas welders, 144 (5.4%) mining foremen, 85 (3.2%) tunnellers and other 980 workers of trades with fewer people employed. It should be noted that the above-mentioned division into trades is arbitrary to some extent, since modern miners are trained in 2–4 trades and can change them depending on production needs.

All underground miners worked in harmful working conditions. The class of working conditions for a tunneller, a borehole driller, an underground miner, a timber-man, a blaster, a vibration-loading machine operator, a crusher was defined as 3.3. For a driller, a loader operator, an underground self-propelled machine operator, an electric locomotive driver, a distributor of explosives, an electric and gas welder, a locksmith and a hatch-man working conditions were assessed as class 3.2. The working conditions of a shaft operator, a hoisting machine operator, a lampman, a miner on geological and mine surveying works, a mining foreman corresponded to class 3.1.

According to the results of routine health screening, 372 (14.0%) employees were considered healthy. The remaining 2 277 (86.0%) miners were diagnosed with 6 778 health disorders. Their number per a worker ranged from one to 13, averaging 2.56 ± 0.05 cases. There was a direct correlation between the number of diseases, the employee's age ($\rho = 0.483$, $p < 0.001$) and employment duration ($\rho = 0.380$, $p < 0.001$). All miners were found fit to continue working in harmful working conditions. However due to suspected potential development of occupational diseases, an additional examination at the regional centre of occupational pathology was recommended to 74 miners.

The diagnosed non-occupational health disorders belonged to 15 categories of ICD-10. The most prevalent were diseases of the musculoskeletal system and connective tissue. Eye and circulatory diseases were detected more than half as often, and the prevalence of the respiratory and digestive diseases was over 4 times less frequent. Diseases of all other categories were diagnosed much less frequently (Table 1).

Ten most frequently detected nosological forms of diseases included myopia (n = 334), arterial hypertension (n = 268), osteoarthritis deformans (n = 240), spinal osteochondrosis (n = 192), varicose veins of the lower extremities (n = 160), arthralgia (n = 144), curvature of the nasal septum with impaired respiratory function (n = 127), flat feet (n = 116), lumbalgia (n = 114) and obesity (n = 91).

Over the next thirteen years, 300 (11.3%) out of 2 649 miners surveyed in 2007 were first diagnosed with 572 occupational diseases, or 1.91 ± 0.07 cases per worker. These included 297 (99.0%) males and 3

Table 1. Non-occupational diseases in underground apatite miners according to annual health screening in 2007.

Disease category	Cases (%)
Diseases of the musculoskeletal system and connective tissue	2 332 (34.4)
Diseases of the eye and its adnexa	1 084 (16.0)
Diseases of the circulatory system	964 (14.2)
Diseases of the respiratory system	540 (8.0)
Diseases of the digestive system	480 (7.1)
Endocrine, nutritional and metabolic diseases	244 (3.6)
Diseases of the skin and subcutaneous tissue	70 (1.0)
Diseases of the genitourinary system	196 (2.9)
Diseases of the nervous system	254 (3.7)
Neoplasms	136 (2.0)
Certain infectious and parasitic diseases	110(1.6)
Diseases of the ear and mastoid process	186 (2.7)
Injury, poisoning and certain other consequences of external causes	118 (1.7)
Symptoms, signs and abnormal clinical and laboratory findings, not elsewhere classified	36 (0.5)
Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism	28 (0.4)

(1.0%) females, whose average age and duration of work at the mine were 51.6 ± 0.4 years and 25.3 ± 0.5 years, respectively. On the whole, occupational diseases diagnoses were based mainly on the findings of routine health screenings (73.7%), their annual percentage varying from 35.5% in 2018 to 100.0% in 2013. In 26.3% of cases, occupational diseases were diagnosed when employees sought medical advice on their own.

In 2008–2020, the annual number of workers diagnosed with occupational diseases varied widely from 24 in 2008 to 10 in 2020, with a maximum (n = 34) in 2012. There was a weak trend (R^2 = 0.4727) towards a decrease in their numbers. However, the number of employees in the cohort was also declining annually due to retirement, dismissal after identification of occupational diseases, and much less frequently due to other non-health related causes. As a result, the ratio between the number of workers with newly diagnosed occupational diseases and the total number of workers in the cohort did not change significantly, with the R-squared value being less than 0.5 (Figure 2). At the same time, the relative risk of occupational disease occurrence in the last four years of the studied period (2017–2020) exceeded the level of the first four years (2008–2011): RR = 1.84; CI 1.16–2.92; χ^2 = 6.82; p = 0.009.

The development of over half of occupational diseases in miners was caused by heavy physical work. Noise, whole-body and hand-arm vibration also played a significant role in their development. Major technological circumstance of occupational disease development (almost two thirds of cases) was imperfection of technological processes. Workplace imperfection and equipment design flaws were almost three times and five times less frequent, respectively, compared with imperfection of technological processes. More than 80% of the occupational diseases of miners developed under working conditions corresponding to classes 3.2 and 3.3. Among four occupational disease cases that occurred under permissible working conditions, three were due to whole-body vibration and one to a chemical factor (chromium dioxide). In extreme working conditions (class 4), hand-arm vibration (over 8 m/s^2) resulted in the development of health disorders in five cases, and in two cases acute poisoning with carbon monoxide occurred.

Chronic diseases (n = 489) accounted for 98.6% of the total number of diagnosed occupational health disorders and nearly half of them were musculoskeletal diseases. Injuries, diseases of the nervous system and ear diseases were diagnosed less often, and in isolated cases – respiratory diseases. In 2 (0.4%) cases, chronic poisonings with harmful substances were detected. One was caused by nitrogen dioxide and the other was due to exposure to manganese compounds in welding fumes. Five most prevalent nosological forms of occupational diseases included effects of vibration, radiculopathy, osteoarthritis deformans, mono- and polyneuropathies, and noise effects on inner ear. They accounted for 81.7% of health disorders (Table 2).

For 13 years, occupational diseases were first diagnosed in workers of 29 trades. The peculiarities of occupational pathology development were studied in miners of 9 different trades with 10 or more diseases (Table 3).

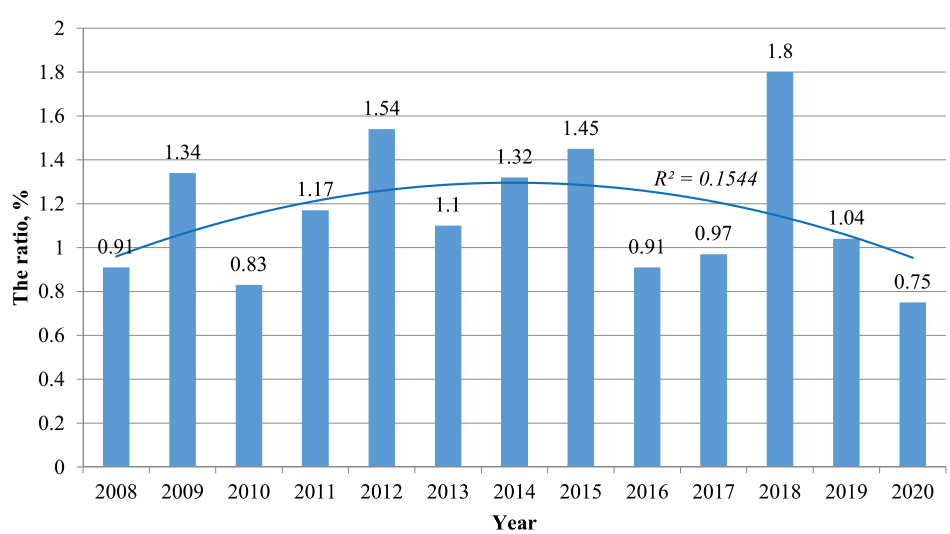

Figure 2. The ratio (%) between the number of workers with newly diagnosed occupational diseases and the total number of workers in the cohort in 2008–2020.

Significantly more often ($p < 0.001$), health disorders developed in tunnellers (50.6% of workers in this trade), drillers (33.7%), timber-men (32.4%) and vibration-loading machine operators (29.7%) as compared to underground miners (10.8%) and electric and gas welders (4.0%). Locksmiths (electrical fitters) who were the most numerous group of miners also had a very low number of occupational diseases: four cases among 546 (0.7%) workers. At the same time, no diseases were diagnosed in such widespread occupations as a shaft operator, a hoisting machine operator, an explosive preparation operator, a lampman, a geological miner, and a number of others. However, it should be taken into account that the figures given are approximate due to the fact that many miners during their professional careers are listed as workers in various trades.

The minimum age of occurrence of occupational diseases was reported in tunnellers (34 years old) and underground miners (35 years old), while in electric gas welders, diseases were detected only in persons aged 50 years and older. The average age of tunnellers with occupational pathology was 4–8 years less than that of workers in other specialities. Cases of the shortest employment duration preceding the development of an occupational disease were noted in electric locomotive drivers (11 years) and tunnellers (10 years), and the maximum duration was in electric and gas welders (24 years), underground miners and loader operators (15 years each). For tunnellers, the average employment duration resulting in occupational disease development was 4–10 years shorter than that in workers of other trades.

The largest annual number of cases of occupational diseases (per 10 000 workers of each speciality) was observed in tunnellers (714.9 cases), timber-men (610.9 cases), drillers (541.6 cases) and blasters (510.1 cases). This indicator was the lowest among underground miners (88.9 cases) and electric and gas welders (51.3 cases). Overall, the annual occupational disease incidence at the underground mine was 166.1 cases per 10 000 workers. The tunnellers had the highest risk of developing occupational diseases. It exceeded that of all other miners, including timber-men (RR = 1.56; CI 1.06–2.30; $p = 0.024$), vibration-loading

Table 2. General characteristics of newly diagnosed occupational diseases in underground apatite miners.

Indicator	Cases (%)
Disease category	
Diseases of the musculoskeletal system and connective tissue	270 (47.2)
Injury, poisoning and certain other consequences of external causes	119 (20.8)
Diseases of the nervous system	95 (16.6)
Diseases of the ear and mastoid process	77 (13.5)
Diseases of the respiratory system	11 (1.9)
Most prevalent nosological forms	
Effects of vibration	112 (19.6)
Radiculopathy	110 (19.2)
Osteoarthritis deformans	89 (15.6)
Mono- and polyneuropathies	79 (13.8)
Noise effects on inner ear	77 (13.5)
Epicondylitis of the humerus	35 (6.1)
Myofibrosis of the forearms	27 (4.7)
Casual factors	
Heavy physical work	347 (60.7)
Noise	77 (13.5)
Whole-body vibration	70 (12.2)
Hand-arm vibration	58 (10.1)
Chemicals of I–IV hazard classes	18 (3.1)
Fibrogenic aerosols	2 (0.3)
Casual circumstances	
Imperfection of technological processes	362 (63.3)
Imperfection of workplaces	133 (23.2)
Design flaws of machines, mechanisms and other equipment	72 (12.6)
Breach of technological regulations	3 (0.5)
Breach of safety regulations	2 (0.3)
Total class of working conditions	
Permissible (class 2)	4 (0.7)
Harmful (class 3.1)	56(9.7)
Harmful (class 3.2)	362 (63.3)
Harmful (class 3.3)	105 (18.4)
Harmful (class 3.4)	38 (6.6)
Extreme (class 4)	7 (1.2)

Table 3. Characteristics of occupational diseases in underground apatite miners of various trades in 2008–2020.

Indicator	Blaster	Tunneller	Loader operator	Locomotive driver	Driller	Timber-man	Underground miner	Vibro-loading machine operator	Electric and gas welder
Total number of employees	190	85	158	223	98	68	173	37	150
Number (%) of employees with occupational diseases	52(27.4%)	43(50.6%)	39(24.7%)	42(18.8%)	33(33.7%)	22(32.4%)	12(10.8%)	11(29.7%)	6(4.0%)
Mean age ± SEM at detection of occupational disease, years	53.9±0.6	46.3±0.8	50.6±0.7	54.7±0.7	50.1±0.7	53.3±0.7	52.1±2.4	52.3±1.1	54.9±1.5
Minimum age at detection of occupational disease, years	38	34	37	37	43	45	35	44	50
Mean ± SEM experience at detection of occupational disease, years	28.0±0.7	20.4±0.7	24.8±0.8	26.1±1.0	25.1±0.8	25.7±1.0	24.2±2.2	27.0±1.4	29.9±1.9
Minimum experience at detection of occupational disease, years	12	10	15	11	12	13	15	14	24
Number of diseases	126	79	80	60	69	54	18	18	10
Number of diseases per year per 10,000 employees	510.1	714.9	389.5	207.0	541.6	610.9	88.9	374.2	51.3

In the line "Number of employees with occupational disease" % means the proportion of workers with occupational diseases in the total number of workers in this trade.

machine operators (RR = 1.67; CI 0.99–2.80; $p = 0.034$), drillers (RR = 1.51; CI 1.08–2.11; $p = 0.034$) and blasters (RR = 2.12; CI 1.55–2.84; $p < 0.001$).

We found no significant differences in the risk of developing occupational diseases between the timber-men, vibration-loading machine operators, drillers and blasters, as well as between loader operators and electric locomotive drivers. For drillers and timber-men the risk of occupational disease formation was higher than that for electric locomotive operators. Workers of all trades, except underground miners, had a higher risk of occupational diseases than that for electric and gas welders. The results of pairwise comparison of occupational disease risks in nine studied groups of workers are presented in Table 4.

Discussion

The results of the presented study show that the underground apatite miners in the Kola Arctic continue to be at high risk of developing occupational diseases. Moreover, their occupational morbidity rates are many times higher than the all-Russian levels in all types of economic activity, and in ore mining [13,14,23,24]. The obtained results were very close only to the results of a study using a posteriori occupational morbidity data at Uchalinsky mining company (in the Republic of Bashkiria, Russia) in 1975–2000: 3.2 cases per 100 workers who participated in annual routine health screenings [25]. Unfortunately, we did not have the opportunity to compare occupational morbidity levels of apatite miners in Russia and other countries due to unavailability of such information in the scientific literature.

Among the Kola Arctic underground apatite miners, the greatest risk of health problems was identified among the tunnellers. For thirteen years, a half of the workers in this trade have been diagnosed with occupational diseases. Somewhat less frequently (approximately in one third of employees over 13 years), occupational pathology occurs in timber-men, vibration-loading machine operators and drillers. It is noteworthy that the Kola Arctic miners have an increased risk of developing occupational diseases with employment duration starting from 10 years and at the age of 34–35 years, and not from 20 and 50 years, respectively, as among miners in Russia in general [11,14].

It is believed that in the northern mines, partly due to cold environment, working conditions are more difficult than in mines in other regions of the country [2,6]. The role of low temperature in the surveyed group of workers seems to be underestimated, since no cases of occupational diseases have been linked to this. This is probably a consequence of both the shortcomings of the assessment method and an incomplete understanding of the negative effect of local and whole-body cooling on human body, including the musculoskeletal system [4,14].

Musculoskeletal diseases most often had occupational aetiology in the Arctic underground apatite miners. If their percentage in the structure of non-occupational diseases accounted for 34.4%, then among occupational diseases it reached 47.2%. This emphasises the need for early targeted prevention of musculoskeletal diseases already at the initial stages of the professional career of miners [5,23]. A specific feature of the occupational diseases of the studied group of workers was a smaller proportion of chronic

Table 4. Pairwise comparison of occupational disease risks in miners of nine trades.

Indicator	Tunneller	Timber-man	Vibro-loading machine operator	Driller	Blaster	Loader operator	Locomotive driver	Underground miner	Electric and gas welder
Tunneller	-	1.56	1.67	1.51	2.12	2.05	2.69	7.29	12.65
		0.017	0.034	0.031	<0.001	<0.001	<0.001	<0.001	<0.001
Timber-man	0.64	-	1.09	0.96	1.18	1.31	1.72	4.88	8.09
	0.017		0.783	0.859	0.436	0.234	0.019	<0.001	<0.001
Vibro-loading machine operator	0.59	0.92	-	0.88	1.09	1.20	1.58	4.29	7.43
	0.034	0.783		0.664	0.770	0.528	0.128	<0.001	<0.001
Driller	0.67	1.04	1.13	-	1.23	1.36	1.79	4.85	8.42
	0.031	0.859	0.664		0.267	0.121	0.004	<0.001	<0.001
Blaster	0.54	0.85	0.92	0.81	-	1.11	1.40	3.72	6.45
	<0.001	0.436	0.770	0.267		0.571	0.070	<0.001	<0.001
Loader operator	0.49	0.76	0.83	0.73	0.90	-	1.31	3.28	6.17
	<0.001	0.234	0.528	0.030	0.571		0.170	<0.001	<0.001
Locomotive driver	0.58	0.51	0.63	0.56	0.71	0.76	-	2.65	4.60
	<0.001	0.019	0.128	0.004	0.070	0.170		0.001	<0.001
Underground miner	0.14	0.21	0.23	0.21	0.27	0.30	0.38	-	1.73
	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001		0.252
Electric and gas welder	0.07	0.12	0.13	0.12	0.16	0.16	0.22	0.58	-
	<0.001	<0.00	<0.001	<0.001	<0.001	<0.001	<0.001	0.252	

Upper line – the relative risk values; Bottom line – p-values (significance level).

bronchopulmonary pathology (2.0% compared to 30.1% on average in underground mines in Russia) [13].

It is not always possible to explain the occupational morbidity rates among miners by the degree of harmfulness of their working conditions. Thus, in some groups of miners with the same working conditions of class 3.2, occupational diseases are diagnosed extremely rarely (for example, in 0.7% of locksmiths), in other groups – rarely (in 4.0% of electric and gas welders), while in other workers they occur very often (in 24.7% of loader operators). Apparently, it is not the class of working conditions that is of top importance, but the specific impact of certain occupational hazards and the individual characteristics of the worker's health. In addition, the majority of miners are trained in two to four trades, the change of which can significantly influence the class of working condition.

We pay attention to the significant annual fluctuations in the number of detected cases of occupational diseases in miners. The reason for this phenomenon may be shortcomings in the organisation and carrying out of annual health screening procedures, incomplete detection of diseases or their diagnosis at the late stages of development, different opinions of expert doctors on the aetiology and nature of miners´ health disorders [13,14].

The revealed features of age and employment duration in the development of occupational diseases, information on occupational hazards and the nature of previously identified non-occupational and occupational diseases will make it possible to more accurately and timely determine the degree (from low to very high) of occupational risk. Such a risk-oriented approach will allow for more differentiated and targeted implementation of preventive and health-improving measures for underground apatite miners of various trades.

It is necessary to note the confounders and limitations of the research performed. We consider unhealthy behavioural factors (smoking, alcohol abuse, unhealthy diet, and others) as likely confounders. They are well known to have a significant negative impact on the working population health and can thus contribute to the development of occupational diseases. Therefore, we are going to devote the next stage of our research to the study of the joint influence of occupational hazards and behavioural factors on the formation of health disorders in Russian Arctic miners. The limitation of this study is that it is not possible among former miners to completely exclude cases of occupational diseases diagnosed outside the Murmansk region. This applies to persons who have dropped out of the study cohort within 13 years due to retirement, relocation to a new place of residence or job change. However, given the existing practice of identifying occupational diseases in Russia, this is extremely unlikely. Therefore, former employees leave for a new place of residence or change jobs only after the official registration of an occupational disease takes place.

Conclusions

During the 13-year period of monitoring the health of the underground apatite miners in the Kola Arctic, it was found that the maximum risk of occupational disease development is observed in tunnellers. The risk is lower for timber-men, drillers, vibration-loading machine and rig operators, blasters, loader operators and locomotive drivers. The risk of occupational disease development in electric and gas welders, locksmiths and workers of all other trades is even lower. For the first time, an increase in the risk of occupational diseases occurs with employment duration of 10 years and at the age of 34–35 years. The largest percentage of occupational health disorders were musculoskeletal diseases (47.2%), which stresses the need for their early targeted prevention. In general, the modernisation of ore mining processes and the current system of medical preventive measures do not provide sufficient health care for Arctic underground apatite miners. Achieving this goal requires more effective labour protection combined with health risk-based medical interventions.

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ORCID

Sergei A. Syurin http://orcid.org/0000-0003-0275-0553
Aleksandr A. Kovshov http://orcid.org/0000-0001-9453-8431
Jon Ø. Odland http://orcid.org/0000-0002-2756-0732

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