RESEARCH ARTICLE

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Carcinogenic Risk Assessment and Changes in Spirometric Indices in Casting and Welding Workers Exposed to Metal Fumes

Somayeh Rahimimoghadam[1], Mohamad Nasser Layegh Tizabi[2], Narges Khanjani[3], Mojtaba Emkani[4]*, Ali Ganjali[5]

Abstract

Introduction: The aim of this study was to investigate exposure to dust, and metal fumes, changes in pulmonary function indices among industrial workers to estimate the carcinogenic and non-carcinogenic risk of exposure to occupational metal fume. **Methods:** This cross-sectional study was performed on 98 workers exposed to metal fumes. Air sampling was performed according to the NIOSH 0500 method and was analyzed by gravimetry and metal levels were analyzed by atomic absorption spectrometry. Spirometric results for 2010-2016 were collected. Carcinogenic and non-carcinogenic risk assessments were performed according to the US Environmental Protection Agency guidelines. Data were analyzed by SPSS 20 software. **Results:** The mean occupational exposure of the subjects to workplace dust and iron fumes was 15.95 ± 6.65 mg/m3 and 13.18 ± 3.06 mg/m3 respectively. During these 6 years, the FVC (P=0.04), PEFR (P=0.04), and FEV1 (P=0.03) indices decreased significantly among welders, but there was no significant difference between FEV1/ FVC indexes. Also, the mean of FEV1 and PEFR decreased significantly amongst casting workers, but FVC and FEV1/ FVC had no significant difference. Multivariate regression showed that in both jobs, BMI and work history were related to pulmonary function indices. The mean total excess lifetime carcinogenic risk (ELCR) of hexavalent chromium in the study population was 0.708 per 1000 people and the mean non-carcinogenic risk of hexavalent chromium was HQ = 19.62. **Conclusions:** The results showed that exposure to metal fumes in casting and welding jobs reduced pulmonary function indices. Although the average occupational exposure to hexavalent chromium was lower than the recommended limit and the risk of carcinogenesis was within an acceptable range, the risk of non-carcinogenic effects among workers is significant Therefore, it is important to prevent this problem, by adequate ventilation and using respiratory masks.

Keywords: Metal fumes- pulmonary function indices- occupational exposure- risk assessments- carcinogenic

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Introduction

Occupational respiratory diseases are one of the most common occupational diseases. These diseases are usually asymptomatic for a long time and are diagnosed in late stages, which make treatment efforts less effective(Rahimi Moghadam et al., 2020). Most acute and chronic pulmonary diseases can be caused by inhalation of hazardous chemical agents in the workplace including dust, toxic particles, metal fumes, gases, vapors, and other occupational airborne pollutants(Kachel, 2003; Taheri et al., 2021). Mineral dust has various constituents and can cause different diseases in different people because of its individual biological characteristics. Long-term exposure to these chemicals can cause chronic diseases such as asthma, chronic bronchitis, lung fibrosis, and eventually lung cancer (Laden et al., 2006; Ballester et al., 2008). According to recent reports, approximately 2.4 million industrial workers in the US are exposed to crystalline silicate, asbestos, and other toxic particles and dust (Dominici et al., 2007). Studies show that about 30-40% of asthma cases and 20-30% of all respiratory diseases can be related to exposure to suspended particles (Elliott et al., 2007).

The steel industry is one of the biggest industries in Iran and Neyshabur city with 400 factories, 3 industrial towns, and big industries like Iran Khodro, and the steel industry is considered as one of the industrial

[1]*Department of Occupational Health Engineering, Neyshabur University of Medical Sciences, Neyshabur, Iran.* [2]*Environmental Health Engineering Research Center, Kerman University of Medical Sciences, Kerman, Iran.* [3]*Department of Medical Education, Paul L. Foster School of Medicine, Texas Tech University Health Sciences Center El Paso, Texas, USA.* [4]*Student Research Committee, Shiraz University of Medical Sciences, Shiraz, Iran.* [5]*Student Research Committee, Neyshabur University of Medical Sciences, Iran. *For Correspondence: mojtabaemkani@gmail.com*

hubs in the east of Iran. One of the most important occupational hazards that workers in the steel industry face are exposure to chemicals and metal fumes such as iron oxide, magnesium, cadmium, chromium, zinc, manganese, and gases such as nitrogen oxide and carbon monoxide during welding, casting, loading and unloading materials(Rahimi Moghaddam and Khanjani, 2014). Most of these materials are in the form of vapor and fine particles with diameters in the range of 0.5 to 2.5 μm and can penetrate deep into the lungs, and reach the alveoli(Rahimi Moghaddam and Khanjani, 2014). Diseases such as chronic bronchitis, emphysema, cardiovascular disorders, metal fume inhalation fever, gradual reduction of FEV1, FEF25-75%, and FVC pulmonary function indices, and lung cancer have been reported in workers exposed to metal fumes(Ameille, 2010). A study by Aminian et al conducted in 2012 on welders working at a car factory in Tehran, showed decreased pulmonary function indices in workers after 4 years of welding and exposure to metal fumes(Aminian, Beheshti and Atarchi, 2003). Also, Abedi et al. reported that in Ardabil city welders, there was a significant decrease in pulmonary function indices (FVC, FEV1, and FVC / FEV1) in the group exposed to metal fumes compared to the control group(Abedi A., Sazavar H., 2004).

Exposure to heavy metals is one of the most important occupational risks for workers in the foundry industry (Mohammadyan, Moosazadeh, Borji, Khanjani and Rahimi Moghadam, 2019). One of the most hazardous of these metals is chromium, which according to the classification of the International Agency for Research on Cancer (IARC), hexavalent chromium is in group A1 (definitive carcinogen) (IARC, 1987). Skin ulcers, irritation of nasal mucosa, perforation of the nasal septum, irritation of the gastrointestinal tract, damage to the sense of smell and discoloration of the tongue, and yellow teeth are symptoms of hexavalent chromium toxicity (Grote, 1994). Numerous methods have been proposed to assess the health of humans exposed to chemicals in the workplace (Sadovska, 2012; Dehghani et al., 2021).

One of the most important tools in the diagnosis of occupational pulmonary diseases is spirometry tests. Spirometry is an accessible and cheap method for evaluating workers' pulmonary function and can show respiratory diseases in their early stages when there is still a possibility to prevent their progress(Rahimi Moghaddam and Khanjani, 2014; Rahimi Moghadam et al., 2020).

Risk assessment is one of the methods for assessing the risk of employees facing specific exposures. Risk assessment in addition to estimating the risk of carcinogenicity includes estimating the non-carcinogenic risk ratio, which is an estimate of health effects other than cancer.

Considering the importance of recognizing and controlling hazardous compounds in work environments, in the present study the risk of developing cancer and non-cancerous diseases, and changes in lung parameters of workers exposed to hexavalent chromium, over a 6-year period, has been estimated.

Materials and Methods

Study population

This research was a cross-sectional study evaluating the situation of 27 welders and 72 casting workers, working in the Neyshabur city steel industries, in 2016.

There were more than 1,500 workers in this industry; in which 110 workers were working in the smelting, casting, and welding units. All workers were invited to participate. The study objectives were explained for them and workers consented to participate.

Workers who had been employed in the welding and casting profession for at least 6 years and had spirometric tests for the years 2010, 2012 and 2014 were enrolled and then a spirometric test was conducted by a medical practitioner in Neyshabur in 2016. Workers with contraindications for spirometry, including systolic blood pressure greater than 180/100 mmHg, pulmonary tuberculosis, history of heart attacks or angina, history of stroke, history of the chest and abdominal surgery, recent eye or ear surgery, active hemoptysis, respiratory distress, abdominal aortic aneurysm, history of surgery, recent illness, flu, bronchitis or pneumonia for the past 3 weeks, eating heavy food in the 2 hours before the test were excluded. Also, workers who were smokers, were engaged in other occupations before employment in welding or casting workshops or had a second job, which could have affected spirometric results even after several years were excluded.

Pulmonary function tests

After applying the inclusion and exclusion criteria, 99 people (27 welders and 72 casting workers) entered the study. A questionnaire including demographic information, smoking status, and work history was completed for each worker. A new spirometry was performed according to the guidelines of the American Lung Association and using the Vitalograph Compact spirometer that was calibrated twice, first at starting and second every four hours. It was calibrated by a trained medical practitioner. The spirometries were conducted for all workers under the same standard conditions.

Air monitoring

A total of 98 air samples were taken from the workers' respiratory zone, by using the PCMTX8, SKC, UK PCMTX8 individual sample pump and cellulose ester filter (model 225-19, SKC, UK) with a diameter of 37 and 0.8 microns pore size, and according to the NIOSH0500 method(Grote, 1994). Initially, the individual sampling pump was calibrated by a soap bubble flowmeter, and then the filters were inserted into the holder and placed in the workers' respiratory zone. The sampling rate was 1.7 L/min for 2 hours during the working shift. In order to remove the moisture content of the filter, the filters were placed in a desiccator before and after sampling for 24 hours. Filters were then weighed by a CP225D Sartorius digital scale and the weight was reported with 5 decimals. A control sample was taken per every 10 real samples. The amount of inhalable dust was then calculated using the following equation 1:

$$C(mg/m^3)=\frac{(W2-W1)-(B2-B1)}{V}\times 10^3$$

W1= tare weight of filter before sampling (mg),
W2= post-sampling weight of sample-containing filter (mg),
B1= mean tare weight of blank filters (mg),
B2= mean post-sampling weight of blank filters (mg)

According to field studies and random samples taken in this industry, it was found that the amount of occupational exposure to hexavalent iron and chromium fumes was considerable, but other metals were present in very small and negligible amounts. Therefore, in this study, only iron and chromium were studied. Due to the fact that chromium is a known carcinogen, a carcinogenic risk assessment was performed for only this compound.

In order to determine the amount of iron and chromium in the samples, the filters were dissolved by using concentrated nitric acid (HNO_3) and per chloric acid ($HClO_4$) at a volume ratio of 4:1. For this purpose, after opening the filter holder, the filter was placed in a 100 ml beaker, 5 ml of concentrated nitric acid and per chloric acid was added, and the beaker was closed with a glass lid for 30 minutes, at room temperature. Then the sample was placed on the stove at 120°C until its volume decreased to 0.5 ml. This step was repeated several times by adding 2 ml of the solution and was continued until the solution was clear. Finally, the solution was filtered with Watkins 40 paper and injected into the WFX-130 RAYLEIGH Atomic Absorber device, made in China. In order to do the analysis, the standard solution of iron with the analytical grade of the Merck Company, was prepared with 99.99% purity; and standard solutions were prepared with concentrations of 1, 5, 10, 20, 40, 80, 100 ppm; and were then injected into the atomic absorption device and the standard curve was drawn. Then the main samples were injected into the device and according to the standard curves, the concentration of the chemicals was determined in the real samples.

Carcinogenic risk assessment

The quantitative risk of carcinogens is calculated using the OEHHA method, based on the exposure rate and the unit of risk level (URL), in which is a specific value for each substance. The final number obtained from the following equation indicates the number of cancers, due to exposure to a special substance, under specific exposure conditions, per 1,000 people (Mohammadyan et al., 2019).

$$ELCR=TWA\times\frac{H\ hours}{24\ hours}\times\frac{5\ days}{7\ days}\times\frac{50\ weeks}{52\ weeks}\times\frac{30\ years}{70\ years}\times UR \text{ - Excess Lifetime Cancer Risks}$$

(Equation 2)

ELCR: Risk of cancer increase throughout life per thousand, TWA: average of pollutant time weight in terms of $\mu g/m^3$ for hexavalent chromium (50 $\mu g/m^3$), H: hours worked per day, URL: unit level of risk for lead (1.50×10^{-1} $\mu g/m^3$).

Quantitative non-carcinogenic risk assessment

To calculate the non-carcinogenic risk, first, the Exposure Concentration (EC) is calculated, and finally, the Hazard Quotient (HQ) is calculated from Equations 3and 4. An HQ greater than 1 indicates a non-cancerous complication and an HQ less than or equal to 1 indicates that the contaminant concentration is less than the standard limit concentration (RfC) and is not expected to cause any harm to individuals . The variables required to assess the non-carcinogenic risk are presented in Table 1.

$$EC=\frac{(CA\times ET\times EF\times ED)}{AT}$$ (Equation 3)

$$HQ=\frac{EC}{RfC}$$ (Equation 4)

Data were entered into SPSS20 software. The normality of the data was checked by the Kolmogorov-Smirnov test and histograms. Statistical analysis was performed by t-test to measure the difference between lung indexes and demographic characteristics, such as age, job experience, and BMI between the two occupational groups. Repeated measures were used to determine the changes in pulmonary function indices over the years in welders and casting workers. Univariate and multivariate regression were used to determine the influence of different factors on pulmonary function indices. The significance level was considered 0.05.

Results

The mean age of the 98 subjects was 35.48 ± 7.02 and they were in the 30-49 age range. Their average work history was 11.58 ± 4.11 in a range of 10 to 22 years. Their mean height was 174.02 ± 4.77 (range:158-181), mean weight was 68.03 ± 7.09 (range: 60-110), and mean BMI was 26.87 ± 9.02 (range: 18.7-37).

The results of the present study showed that their average exposure to total workplace dust was 15.95 ± 6.65 $\mu g/m^3$ with a range of 3.59 and 18.31 $\mu g/m^3$. The average occupational exposure to metallic iron fumes was 13.18 ± 3.06 $\mu g/m^3$ with a range of 3.02-14.02 $\mu g/m^3$

Table 1. Risk Factor Variables

Variable	Definition	Unit	Basis
CA	Chemical concentration	$\mu g/m^3$	Sampling
ET	Exposure time	hours/day	8 (working hours)
EF	Exposure frequency	days/year	Questionnaire
ED	Exposure duration	years	Questionnaire
AT	Average time	days	(ED × day × hour)
RfC	Inhalation reference	$\mu g/m^3$	For chromium 0.1 (IRIS)

Table 2. Spirometric Index Changes Over the Years

Job	Years	FVC (liter)	FEV1 (liter)	FVC/FEV1	PEFR (liter/min)
Welder	2010	4.46	4.18	87.6	7.83
	2012	4.4	4.13	83.62	7.14
	2014	4.1	4.06	85.7	6.7
	2016	3.76	3.1	83.23	6.31
	p-value	0.04*	0.03*	0.06	0.04*
Casting worker	2010	4.19	3.94	81.95	6.47
	2012	4.2	3.24	81.75	6.24
	2014	4.06	3	81.85	5.1
	2016	4.1	2.46	75.26	5.07
	p-value	0.07	0.02*	0.08	0.01*
Total	2010	4.32	4.06	84.77	7.15
	2012	4.3	3.68	82.68	6.69
	2014	4.08	3.53	83.77	5.9
	2016	4.93	2.78	79.24	5.69
	p-value	0.55	0.041	0.32	0.045

and average occupational exposure to chromium was 20±0.06 μg/m^3 with a range 0.1-39 μg/ m^3.

The FEV1, FVC/FEV1, and PEFR pulmonary function indices decreased significantly among the 98 workers during the years.

All of the pulmonary function indices were significantly different between welders and casting workers on the years under study and the average indices in welders were higher than the casters. The results of the study showed that the FVC, PEFR and FEV1 parameters decreased significantly among the welders during these years; and the mean of FEV1 and PEFR significantly decreased amongst the casting workers (Table 2).

The effects of factors such as age, job history, BMI, and occupation were also assessed on pulmonary function indices. Results of multivariate regression showed that age was not significantly correlated with the FVC, FEV1, and FEV1/FVC indices, but was directly and significantly correlated with PEFR (β=0.36, P=0.02), and with an increase in age, PEFR increases as well. Body mass index was also directly and significantly correlated with FEV1 (β=0.27, P=0.01), and PEFR (β=0.23, P=0.04). But, work history was not significantly correlated with any of the pulmonary function indices. There was a significant relation between job type and FEV1 (β= 0.35, P=0.02), FEV1 / FVC (β = -0.52, P = 0.03) and PEFR (β = -0.21, P = 0.04) (Table 3).

The mean total lifetime carcinogenic risk (ELCR) of hexavalent chromium in the study population was 0.708 per 1,000 people and the mean non-carcinogenic risk of hexavalent chromium was HQ = 19.62.

Table 3. The Effect of Variables on Pulmonary Function Indices

Pulmonary function indices		Risk factors	Age	BMI	Job experience	Job type
FVC	Univariate	β	-0.03	0.1	-0.05	0.2
		P	0.04*	0.82	0.03*	0.12
	Multivariate	β	-0.05	0.9	0.02	0.06
		P	0.12	0.53	0.34	0.41
FEV1	Univariate	β	0.08	0.04	0.07	-0.01
		P	0.02*	0.04*	0.02*	0.57
	Multivariate	β	0.45	0.23	0.69	0.35
		P	0.07	0.04*	0.22	0.02*
FEV1/FVC	Univariate	β	-0.3	-0.82	-0.25	-0.21
		P	0.26	0.18	0.03*	0.04*
	Multivariate	β	0.11	-0.18	-0.8	-0.52
		P	0.53	0.24	0.55	0.03*
PEFR	Univariate	β	-0.22	0.35	-0.04	-0.005
		P	0.73	0.16	0.02*	0.04*
	Multivariate	β	0.36	0.27	-0.6	-0.21
		P	0.02	0.01*	0.06	0.04*

Discussion

The results of this study showed that the average occupational exposure to total workplace dust in these industries was approximately 1.5 times higher than the recommended NIOSH, OSHA, and ACGIH standards,(American Conference of Governmental Industrial Hygienists (ACGIH®), 2019) which is 10 mg/m^3. In the present study, the average occupational exposure to metallic iron fumes was 3 times higher than the recommended national and international standards, which is 5 mg/m^3. Fani et al.,'s (2016) study among auto parts workers showed that the average concentration of pollutants was 5.561 mg/m^3, which was lower than the permissible limit. The results of the study by Giahi et al., (2014) about exposure to inhalable pollutants in a steel industry showed that the average of total dust particles measured in all units, including furnace, materials, and iron casting was above the permissible limit (120 mg/m^3). Also, the average exposure to ferrous metal fumes was 1.7 times higher than the permissible limit.

Occupational exposure to hexavalent chromium in the present study is 20 micrograms per cubic meter, which is less than the allowable value defined by the international organizations providing occupational exposure standards of 50 micrograms per cubic meter. In Fazli et al.,'s (2016) study, the mean level of exposure in electroplating workers was 29 μg/m^3, and in the Chen et al study on 30 plating workers, average occupational exposure with chromium VI was 2.25 μg/m^3, which in both studies is less than the occupational exposure limit.

Generally, the level of these chemical concentrations is high in these occupations and the slight differences in the reported levels can be due to the workload of the industry, the environmental conditions of the workshops, the position of the workers relative to the sources of pollution, the duration of dust exposure, and the proper use of personal protective equipment and the ventilation of the workshops.

Since exposure to pollutants is above permissible limits in these industries, it is essential to evaluate the pulmonary health of these workers routinely. In this study, pulmonary function indices such as FVC, FEV1, and PEFR in welders; and FEV1 and PEFR in casting workers decreased significantly over the years. In Fani et al.,'s (2016) study, all pulmonary function indices except FVC/FEV1 were significantly lower in the exposure compared to the control group. Rahimi Moghaddam et al.,'s (2014) study about welders in a water heater plant also showed that the average of FEF 25-75%, FEV1/FVC, FEV1, and FVC in welders decreased significantly after 4 years of welding (Rahimi Moghaddam and Khanjani, 2014). Similar to this, the results of the study done by Aminian et al., (1996) about welders working at an automobile factory in Tehran, showed that FVC, FEV1, FEV1/FVC decreased significantly after 6 years of welding. Rossignol et al., (1996) in a cross-sectional study, showed exposure to welding fumes was associated with a decrease in pulmonary function indices. Gholami et al.,'s (2018) study about lung function and spirometry indices among miners in eastern Iran showed that their FVC and FEV1 significantly decreased in exposed groups. The results of the present study are in line with the results of these studies, so it can be concluded that common risk factors among these industries play a role in reducing workers' pulmonary function. These common risk factors are likely to be dust and welding fumes. Minor differences in the pulmonary function indices changes in some groups can be attributed to individual or environmental characteristics.

In this study, the majority of workers did not use proper respiratory protection equipment such as filtered respirators and complained the respirator was heavy and cumbersome and they felt heat and shortness of breath when using the respirator. And because most of the industry under study was outsourced to private contractors and for these contractor's low cost and high production is a priority, there was no regular supervision on workers to use personal protective equipment.

Multivariate test results indicated that body mass index and type of work (welding or casting) had an impact on pulmonary function indices such as FEV1 and PEFR. Various studies have evaluated the effects of variables such as age, work experience, and body mass index and have shown different results. Ramaswamy et al., (2003) showed a significant relation between decreased lung function with increased work experience and increased dust concentrations. A study by Pourtaghi et al., (2009) showed a significant relation between age, work experience, and smoking in welders; and decrease in respiratory indices, and an increase in respiratory symptoms such as cough, sputum, and wheezing. But, a study by Gholami et al., (2018) showed no significant effect for gender, age, height, weight, or work experience on pulmonary function indices and suggested that reduction in pulmonary function indices was mainly related to the dust in the workplace.

According to the EPA standard, the acceptable level of risk in occupational exposure is defined as one in 1,000 (Mohammadyan et al., 2019). Therefore, the risk of carcinogenesis is not high. But the non-cancerous hexavalent chromium risk in this industry and all occupational groups was higher than the standard number 1, and this indicates the high possibility of non-cancerous complications during 70 years of life for all workers in different occupational groups. The non-carcinogenic risk for hexavalent chromium in the study of Fazli et al., (2016) was 123, in which it was 123.89 in hard plating and 19.86 in decorative plating (Fazli et al., 2016).

In the industries evaluated in this present study, workers' physical examinations, including spirometry, audiometry, and blood tests were performed regularly by reputable examiners. Employers were informed about the collected information and monitoring results; in order to improve the situation of the workshop.

One of the limitations of this study was that some medical records were incomplete and some workers were excluded because of this. It is suggested that larger and longer studies be conducted about this job group and the amount of these metals be measured in biological samples of workers so that it provides more reliable results about workers' contamination.

In this study, due to financial constraints, only ferrous metal fumes were measured. In the casting and welding jobs, workers are exposed to a variety of heavy metals, but field surveys and initial tests are done in these industries, revealed that the iron fumes were higher than permitted levels and had priority for research.

In conclusion, the results of the study indicate that exposure to dust and iron fumes was above-permitted levels in this industry; and pulmonary function indices FVC, FEV1, FVC/FEV1, PEFR decreased significantly over the years. Although the average occupational exposure to hexavalent chromium is lower than the recommended limit and the risk of carcinogenesis is within an acceptable range, the risk of non-carcinogenic health effects among workers is significant. Therefore, it is necessary to control these pollutants by using proper ventilation, decreasing exposure time, changing workplaces, and use of appropriate protective equipment.

Author Contribution Statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in the Asian Pacific Journal of Cancer Prevention.

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