ORIGINAL ARTICLE

HEALTH RISK OF OCCUPATIONAL EXPOSURE IN WELDING PROCESSES I. GENOTOXIC RISK

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Summary: The welding processes belong among the important sources of occupational pollutions. The welding fumes are ranked, according to the classification of IARC (International Agency for Research on Cancer), into the group of 2B. In our study we have performed the investigation of twenty men (exposed group) working in the stainless steel welding industrial processes (11 welders and 9 grinders, average age was 31 years, 55 % of smokers, average time period of welding occupational exposure was 8 years). The concentrations of chromium (0.557–16.343 mg/m^3) and nickel (0.340–10.129 mg/m^3) in occupational atmosphere highly exceeded established values of maximum permitted concentrations (0.1 and 1.0 mg/m^3, respectively). The concentrations of manganese did not exceed its permitted values. Total concentrations of 12 polycyclic aromatic hydrocarbons (PAH) in occupational atmosphere varied from 300.9 to 961.2 ng/m^3. For purposes of biological monitoring, the levels of chromosomal aberrations were determined in the exposed and control group. Healthy blood donors servedas a control group. People from that group were not occupationally exposed to harmful chemical compounds (20 men, average age was 36 years, 40 % of smokers). Increased level of chromosomal aberrations of exposed group brought the evidence about higher genotoxic risk of investigated welding processes.

Key words: *Welding; Grinding; Occupational exposure; Health risk; Genotoxicity*

Introduction

The technology of welding process belongs among the well-known pollutant sources of occupational environment (7,12,25). Chromium, nickel and manganese belong among the most presented pollutants (26,27,44). The hexavalent chromium and the compounds of nickel are ranked among the proven carcinogens for human (group 1 according to IARC). Metallic nickel is ranked into the group of substances with supposed carcinogenic effect to human (group 2A according to IARC) (18). The degenerative changes of brain structure belong among the most serious toxic effect of manganese (7,10,23,31). Hazardous are also pneumonitis with higher mortality (7,23,31). Tejral et al. (43,44) presented recurring findings of higher air concentration of polycyclic aromatic hydrocarbons (PAH) at welding processes. PAH represent the largest group of chemical carcinogens produced during burning, pyrolysis and pyrosynthesis of organic matter (2,4,5,9,13,14,19).

Luster et al. (30) classify the PAH and the metals mentioned above as the xenobiotics which can cause the immunosuppression and which decrease the resistance of an organism against infection and tumor cells. In addition to described harmful chemical compounds, the ozone and nitrogen oxides are presented at welding processes, too. Noise, vibrations and all kinds of non-ionizing radiation including UV radiation also belong among the risk physical factors at mentioned processes (7,20,23,31). According to IARC, the welding fumes are classified into the group 2B as a possible humoral carcinogens (18). The aim of presented work is focused on the evaluation of genotoxic effects of occupational exposure at welding processes.

Methods

Investigated groups

For our study a group of 20 workers (men), occupationally exposed to welding fumes was chosen (11 welders, 9 grinders, average age was 31 years, 55 % of smokers, average time period of welding occupational exposure was 8 years). The welding of stainless steel materials has been practiced by WIG method in protective atmosphere of argon. All exposed workers filled the questionnaire oriented to their personal history, occupational anamnesis and non-occupational activities. None of investigated workers has been exposed to harmful (genotoxic) chemical substances out of their work.

At the technologies of investigated industrial plant there was no possibility to select an adequate control group of non-exposed workers. Due to this fact the cytogenetic findings of the exposed group of workers were statistically compared with the findings in a group of healthy blood donors (man), marked as a control group (people of various types of occupations, living at the same locality as people from the exposed group). People from the control group were not occupationally exposed to harmful chemical compounds (20 men, average age was 36 years, 40 % of smokers).

Air analysis

The ambient air samples of exposed welders and grinders were taken during their working shift. The air sample collections were executed by personal sampling apparatus SKC (Sampler Aircheck, type PCXR 224, USA) equipped by filters Synpor 4 (diameter 35 mm). Nearly 70 % of working time was covered by the ambient air monitoring. The concentrations of investigated metals (chromium, nickel, manganese) were determined by the atomic absorption spectrophotometry (AAS). The determination was executed according to the hygienic standard laboratory method (17).

The determination of PAH in occupational air was executed by the method of EPA TO-13 (13). Personal sampling apparatus, described above, collected the air samples. The sample analysis was performed by the high performance liquid chromatography (Hawlet Packard 1050) with the fluorescent detection. In each analyzed air sample the concentrations of 12 chosen PAH were determined (phenanthrene, anthracene, fluoranthene, pyrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenz[a,h]anthracene, benzo[g,h,i]perylene and indeno[1,2,3-cd]pyrene). The total PAH concentrations were calculated as a sum of concentrations of 12 presented PAH.

Chromosomal aberrations

From all persons of exposed and control group the samples of non-coagulated venous blood were taken. The blood samples were analyzed by the standard method of cytogenetic analysis of peripheral lymphocyte (1).

Statistical calculations

For statistic evaluation of our results the “Sigma Stat System” by the Jandel Company (USA) was used. After the control over normality of the data (Kolmogorov-Smirnov test), t-test and non-parametric Mann-Whitney tests were used for the comparison of investigated groups. The statistical process includes the calculation of arithmetic means and standard deviations in particular subsets of analyzed parameters. In the next step, the signification of the differences between calculated means of the subsets was tested.

Results

Air analysis

The concentrations of chromium and nickel in occupational atmosphere of welders and grinders (n = 7) highly exceeded the established values of their maximum permitted concentrations. The concentrations of manganese did not exceed its maximum permitted value (Tab. 1).

Total concentrations of 12 PAH in occupational atmosphere of welders and grinders (n = 2) varied from 300.9 to 961.2 ng/m^3 (Tab. 2). There was no feasibility to compare our results with some permitted values because the maximum permitted concentrations of total (sum) PAH have not been declared. The levels of carcinogenic benzo[a]pyrene were deep below the individual values of its maximum permitted concentrations for occupational environment (11).

Tab. 1: Toxic metals in the occupational atmosphere.

Metals	Range of concentrations (mg/m^3) (n = 7)	NPK-P (mg/m^3)
Chromium	0.557 – 16.343	0.1
Nickel	0.340 – 10.129	1.0
Manganese	0.040 – 1.384	2.0

n = number of analysis
NPK-P = maximum permitted concentrations (11)

Tab. 2: Polycyclic aromatic hydrocarbons (PAH) in the occupational atmosphere.

PAH	Range of concentrations (ng/m^3) (n = 2)
Phenanthrene	278.9 – 900.0
Anthracene	3.7 – 13.1
Fluoranthene	13.5 – 37.2
Pyrene	1.0 – 3.8
Benz[a]anthracene	2.1 – 3.5
Chrysene	1.7 – 2.9
Bezo[b]fluoranthene	1.0 – 1.1
Bezo[k]fluoranthene	<1
Benzo[a]pyrene	<1
Dibenz[a.h]anthracene	<1
Benzo[g.h.i]perylene	<1
Indeno[1.2.3-cd]pyrene	<1
Sum of PAH	300.9 – 961.3

n = number of analysis

Cytogenetic analysis

Twenty people from the exposed group and twenty from the control group were examined for chromosomal aberrations (Tab. 3). In each sample 100 mitotic sets were analyzed. In the exposed group of welders and grinders there were analyzed in a total 2000 cells. From this number, 54 cells (2.70 %) were aberrated. In 12 cases we found the structural aberrations (breaks and exchanges), in 41 cases the polyploidies (numerical aberrations) and one time the endoreduplication (so called “other type of aberrations”). In the control group there were analyzed 2000 cells. From this number 11 cells (0.55 %) were aberrated. The structural and numerical aberrations predominated. The statistic analysis revealed significantly higher level of aberrated chromosomes of peripheral lymphocytes in the group of welders and grinders.

Reference level of chromosomal aberrations for adults in Czech population (n = 20) has been declared in the range from 0 to 1.88 % (1). Final value 2.70 % of aberrated cells at exposed workers (Tab. 3) was found significantly higher when compared with the reference level ($p<0.001$).

Tab. 3: Chromosomal aberrations of peripheral lymphocytes.

Type of aberration (%)		Exposed group (n = 20)	Control group (n = 20)	p – value	Statistic significance
ABB	Mean	2.70	0.55	0.0000181	***
	SD	1.646	0.973		
SAB	Mean	0.60	0.15	0.03109	*
	SD	0.583	0.654		
NAB	Mean	2.05	0.3	0.0000271	***
	SD	1.532	0.458		
JAB	Mean	0.05	0.05	1	NS
	SD	0.218	0.218		

Mean = arithmetic mean
SD = standard deviation
n = number of analyzed subjects
ABB = aberrated cells
SAB = structurally aberrated cells
NAB = numerically aberrated cells
JAB = aberration of another type
*** = $p< 0.001$
* = $p < 0.05$
NS = non significant

Discussion

Selected toxic metals (chromium, nickel and manganese) occurring in the occupational environment of welding manufactures, dispose of significant toxic potential including the carcinogenic potential (8,15,35,36,41,42).

Beside the welding processes, an excessive exposure to chromium can be found also within manufacturing of alloys and during the galvanic metal coating (16.38). It is known that the toxicity of chromium and chrome compounds increases significantly during inhalation of aerosol particles. Welding fumes represent a typical example of aerosol mixture (18,27,28,29,42,44). According to the scientific data, the welding fumes contain from 18 to 26 % of chromium (mostly in a risk hexavalent form) when the work is executed in so-called inert atmosphere. Other types of working atmosphere contain 3–4 % of chromium (7). For a long time the chromium concentrations in welding fumes were not taken as a health risk factor. Lautner et al. (28) measured the concentrations of chromium particles in the occupational atmosphere of stainless steel welders. The volume of these particles creates 1.9–12.3 % of the total volume of welding fumes. At welding technologies of stainless steel, Edme et al. (12) found an average air level of total chromium 201 $\mu g/m^3$. Karlsen et al. (21) described an average concentration of total chromium 120 $\mu g/m^3$ and an average concentration of hexavalent chromium 21 $\mu g/m^3$.

Many analyses of atmosphere of different workplaces (iron foundries, welding manufactures, battery manufactures) showed that the workers are exposed to nickel in a large range, varying from micrograms to milligrams per cubic meter of air (6,7, 21,22). In the occupational environment of welders, Karlsen et al. (21) determined an average nickel concentration 260 $\mu g/m^3$. Very high short-term exposures to chromium and nickel at welding occupational atmosphere were described in the study of Tejral et al. (43). These exposures highly exceeded the maximum permitted concentrations. They varied from hundreds of micrograms to tens of milligrams per cubic meter for chromium and from hundreds of micrograms to units of milligrams per cubic meter for nickel.

As resulted from our findings, the levels of chromium and nickel occurred highly above the maximum permitted concentrations. The total chromium concentrations varied from 0.557 to 16.343 mg/m^3, nickel concentrations from 0.340 to 10.129 mg/m^3. Maximum permitted concentrations achieve the level of 0.1 mg/m^3 for chromium and 1.0 mg/m^3 for nickel.

The occupational exposure to manganese occurs within metallurgy, electrical, glass making and chemical industry. The coal burning and the metallurgy can be designated as main sources of manganese emissions into the atmosphere (7). In the case of manganese exposure, the respiratory tract is assumed as the most important pathway of exposure. Karlsen et al. (21) found in the breathing zones of welders an average concentration of manganese about 14 $\mu g/m^3$. Tejral et al. (43) presented the findings of very high short-term exposures to manganese in occupational atmosphere of stainless steel welding. These values reached tens milligrams per cubic meter and highly exceeded the maximum permitted concentrations for manganese. All the results of manganese level in presented work were under the maximum permitted concentration (2.0 mg/m^3). They varied from 0.040 to 1.384 mg/m^3.

As it was indicated above, it is necessary to take into account the presence of PAH in occupational environment of welding manufactures (13,32,34,43,44). At presented work, the range of PAH levels (300.9–961.2 ng/m^3) corresponded to our previous findings (43,44). However, it must be noted that presented total PAH concentrations significantly exceeded the findings of other authors from machine-industry environment. For example, concentrations of total PAH which were found in the occupational atmosphere of cutting, dispersion hardening and pressing of the metals varied from 66.9 to 106.0 ng/m^3 (3).

Increased levels of chromosomal aberrations indicate the presence of exposure to some genotoxic factor(s) (37,40). Impaired chromosomes of somatic cells increase the risk of tumors and degenerative diseases in human population. In addition, impaired chromosomes affected negatively the functions of cell repair mechanisms and interfere with the process of apoptosis (37,39,40,45).

The cytogenetic analysis of chromosomal aberrations of peripheral lymphocytes often serves as a biological marker of early genotoxic effects of chemical substances. Knudsen et al. (24) described increased levels of chromosomal aberrations of peripheral lymphocytes in workers exposed to high concentrations of chromium in welding atmosphere. Tejral et al. (43) presented higher levels of chromosomal aberrations in peripheral lymphocytes of stainless steel welders. Myslak et al. (33) confirmed the genotoxic effect of chromium and nickel in welding fumes by the test of sisters' chromatides exchange (SCE) in peripheral lymphocytes. In presented study we described significantly higher occurrence of chromosomal aberrations in the exposed group of welders and grinders. It has to be stressed that the workers were exposed to high concentrations of chromium and nickel from their working atmosphere.

Conclusion

The results of biological monitoring, presented by chromosomal aberrations of peripheral lymphocytes, confirmed higher health risk level for workers exposed to high concentrations of toxic metals and PAH in the atmosphere of welding and grinding processes.

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