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Respiratory Symptoms, Immunological Changes, Ventilatory Capacity, and Bronchial Responsiveness in Welders

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Key words: bronchial hyperresponsiveness**;** questionnaire; spirometry; skin prick test; welding.

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Abstract

Objective: To evaluate the effect of workplace exposure and its duration on respiratory symptoms, atopic status, ventilatory capacity, and bronchial responsiveness in welders.

Material and Methods: We performed a cross-sectional study including 39 males working as stainless steel welders and an equal number of male office workers matched by age, duration of employment and smoking status. Respiratory symptoms and detailed smoking history were recorded by questionnaire. Evaluation of examined subjects included skin prick tests to common inhalant allergens, spirometry, and histamine challenge.

Results: We found non-significantly higher prevalence of respiratory symptoms in the last 12 months in welders with significant difference for cough (P = 0.043) and phlegm (P = 0.009). Prevalence of sensitization to common inhalant allergens was similar in both welders and controls. Mean values of spirometric parameters was lower in welders with significant difference for MEF_{50} (P = 0.008) and MEF_{75} (P = 0.000). Prevalence of bronchial hyperresponsiveness (BHR) was higher in welders with significant difference for borderline BHR (P = 0.038). Adverse respiratory effects were more expressed in welders with duration of workplace exposure more than 12 years compared to those exposed less than 12 years.

Conclusion: Our data suggest that workplace exposure in welders may lead to respiratory impairment which is close related to its duration.

Introduction

Welding processes are key components in numerous manufacturing industries. The act of welding relates to merging of two metal or other material particles into one by the melting and cooling processes. Occupational exposure to welding may lead to adverse health effects in exposed workers due to chemical and physical hazards emitted as by-products. Chemical hazards include welding fumes and gases, whereas physical hazards include heat, noise, electrical energy, vibrations, and electromagnetic radiation. The fumes and gases generated during welding are considered to be the most harmful in comparison with other welding by-products [1-4].

Welding fumes are formed by heating the metal above its boiling points and a vapours condensation in very small solid particles. They are chemically very complex and arise primarily from filler metals (e.g. iron, aluminium, cadmium, chromium, copper, lead, nickel, manganese, etc), electrode coating (e.g. lead, cadmium, isocyanates, etc) and cores. Metal oxides particles are particularly hazardous components of welding fumes [1-

3]. Welding gases are produced during welding and cutting processes, which include carbon monoxide, carbon dioxide, ozone, hydrogen fluoride, and nitrogen oxides [2, 3].

Welding fumes and gases are produced at a sufficient rate to cause both short and long-term health effects if not properly controlled. As Antonini indicates, a large number of welders experience some type of respiratory illness, such as airway irritation, metal fume fever, bronchitis, chronic obstructive pulmonary disease, asthma, siderosis and other pulmonary fibrosis (chronic beryllium disease, cobalt lung), lung function changes, an increase in severity, duration, and frequency of pulmonary infections, as well as a possible increase in the incidence of lung cancer. In addition, workplace exposure to welding fumes and gases may also lead to neurological, reproductive, and dermal effects [4, 5].

In the present study we have compared the prevalence of respiratory symptoms and allergic sensitization to common inhalant allergens, values of spirometric parameters, as well as prevalence and severity of bronchial hyperresponsiveness (BHR) between welding workers and office workers in order to assess respiratory impairment related to welding.

Subjects and Methods

Study design and setting

A cross-sectional survey was carried out in a university research laboratory, i.e. Department of Cardiorespiratory Functional Diagnostics at the Institute for Occupational Health of Republic of Macedonia, Skopje - WHO Collaborating Center for Occupational Health and GA^{2}LEN Collaborating Center between September 2009 and October 2010.

Subjects

We examined 39 males aged 36 to 53 years working as stainless steel (SS) welding workers with duration of employment 5 to 22 years (mean duration 12.3 ± 4.9). By duration of employment the examined subjects were divided in two subgroups: employed (exposed to welding fumes and gases) less and more than 12 years.

The welders worked in a metallurgic plant in two work shifts, each of them lasted 8 hours. Their working tasks included welding and cutting SS, i.e. steel containing nickel and chromium, which was performed in a large, closed and ventilated working area. The welding technique used is known as a flux core arc welding, i.e. welding method used for carbon steels, low alloy steels and SS. In this welding process the consumable electrode (the welding rod) is continuously fed from a spool and an electric arc flows between the electrode and base metal. The electrode wire has a central core containing fluxing agents while additional shielding gas may be supplied externally. During this type of welding a large amount of fumes is generated due to the high electrical currents and the flux-cored electrode. On the other hand, this welding process generates little ozone and nitrogen oxides. During the work shift the welding workers used protective clothing, gloves, masks, and protective equipment for the eyes.

In addition, a group of male office workers matched to welding workers by age, duration of employment, and daily smoking was studied as a control.

The subjects with chronic respiratory disease diagnosed by physician were excluded from the study. In either group there were no subjects in whom histamine challenge was contraindicated [6, 7], nor there were subjects with the respiratory viral infection within three weeks before the challenge test was performed. None of the subjects took asthma medications or antihistamines at least one month before the challenge test and skin prick tests. Current smokers were asked to restrain from smoking at least 3 hours before testing. All study subjects were informed about the study, and their written consent was obtained.

Questionnaire

All subjects were interviewed by a physician who filled the questionnaire. The questionnaire also included questions on work history, respiratory symptoms in the last 12 months, and smoking status of the study subjects.

The work histories of the study subjects were assessed through questions on previous and current job, daily working time, job description, working conditions, ventilation conditions, and use of protective measures and equipment.

Respiratory symptoms in the last 12 months (cough, phlegm, dyspnoea, wheezing, and chest tightness) were documented using the European Community for Coal and Steel questionnaire (ECCS-87), and the European Community Respiratory Health Survey (ECRHS) questionnaire [8, 9].

Detailed smoking history, accompanying disease, and medication use were also evaluated.

Classification of smoking status was done according to the World Health Organization (WHO) guidelines on definitions of smoking status [10].

Current smoker was defined as a subject who smoked at the time of the survey at least once a day, except on days of religious fasting. In current smokers lifetime cigarette smoking and daily mean of cigarettes smoked were evaluated. Pack-years smoked (one pack-year denotes one year of smoking 20 cigarettes per day) were calculated according to the actual recommendations [11].

Ex-smoker was defined as a formerly current smoker, no longer smokes.

Passive smoking or exposure to environmental tobacco smoke (ETS) was defined as the exposure of a person to tobacco combustion products from smoking by others [12].

Skin prick tests

Skin prick tests (SPT) to common inhalant allergens were performed in all subjects on the volar part of the forearm using commercial allergen extracts (Torlak, Serbia) of birch (5000 PNU), grass mixed (5000 PNU), plantain (5000 PNU), fungi mixed (4000 PNU), *Dermatophagoides pteronyssinus* (3000 PNU), dog hair (4000 PNU), cat fur (4000 PNU), and feathers mixed (4000 PNU). All tests included positive (1 mg/mL histamine) and negative (0.9% saline) controls. Prick tests were considered positive if the mean wheal diameter 20 min after allergen application was at least 3 mm larger than the size of the negative control [13]. Atopy was defined as the presence of at least one positive SPT [14].

Spirometry

Spirometry, including measures of forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), FEV_1/FVC ratio, and maximal expiratory flow at 50%, 75%, and 25-75% of FVC (MEF_{50}, MEF_{75}, and MEF_{25-75}, respectively), was performed in all subjects using spirometer Ganshorn SanoScope LF8 (Ganshorn Medizin Electronic GmbH, Germany) with recording the best result from three measurements of FEV1 values, within 5% of each other. The results of spirometry were expressed as percentages of the predicted values according to the European Community for Coal and Steel (ECCS) norms [15].

Histamine challenge

The histamine challenge test was performed according to the actual European Respiratory Society (ERS)/American Thoracic Society (ATS) recommendations [6, 7]. Concentrations of 0.5, 1, 2, 4, and 8 mg/ml histamine (Torlak, Serbia) were prepared by dilution with buffered saline. The doses of aerosol generated by Pari LC nebulizer with output rate 0.17 ml/min were inhaled by mouthpiece. Subjects inhaled increasing concentrations of histamine using a tidal breathing method until FEV1 fell by more than 20% of its base value (provocative concentration 20 – PC20) or the highest concentration was reached. According to the ATS recommendations, bronchial hyperresponsiveness (BHR) was categorized as moderate to severe BHR (PC20 < 1.0 mg/ml), mild BHR (PC20 = 1.0 – 4.0 mg/ml) and borderline BHR (PC20 = 4.0 – 8.0 mg/ml) [7].

Statistical analysis

SPSS version 11.0 for Windows was used for data description and analysis. Continuous variables were expressed as mean values with standard deviation and categorical variables as numbers and percentages. The chi-square test (or Fisher's exact test where appropriate) was used for testing differences in the prevalence of respiratory symptoms, as well as in the prevalence of allergic sensitization to common inhalant allergens and of BHR. Comparison of spirometric measurements was performed by independent-samples *T*-test. A *P*-value of less than 0.05 was considered statistically significant.

Table 1: Demographics of the study subjects.

Variable	Welders (n = 39)	Office workers (n = 39)
Age (years)	43.9 ± 4.9	44.5 ± 4.2
Duration of employment (years)	12.3 ± 4.9	11.2 ± 5.4
Duration of employment less than 12 years	18 (46.2%)	17 (43.6%)
Current smokers	11 (28.2%)	10 (25.6%)
Life-time smoking (years)	13.8 ± 5.6	14.6 ± 5.0
Cigarettes per day	15.4 ± 7.3	16.6 ± 4.8
Pack-years smoked	10.2 ± 3.8	11.5 ± 2.7
Current smokers with less than 10 pack-years smoked	5 (12.8%)	5 (12.8%)
Ex-smokers	2 (5.1%)	3 (7.6%)
Passive smokers	6 (15.3%)	5 (12.8%)
Accompanying disease		
Arterial hypertension	5 (12.8%)	6 (15.3%)
Peptic ulcer	4 (10.2%)	3 (7.6%)
Diabetes mellitus type 2	2 (5.1%)	3 (7.6%)

Numerical data are expressed as mean value with standard deviation; frequencies as number and percentage of study subjects with certain variable. BMI, body mass index; kg, kilogram; m, meter.

Results

Demographic characteristics of the study subjects were similar in both examined groups (Table 1).

Prevalence of respiratory symptoms within the last 12 months was higher in welders than in controls with statistical significant difference for cough and phlegm (Table 2).

Table 2: Prevalence of respiratory symptoms within the last 12 months in examined groups.

Respiratory symptoms in the last 12 months	Welders (n = 39)	Office workers (n = 39)	*P*-value*
Any respiratory symptom	18 (46.1%)	10 (25.6%)	0.074
Cough	11 (28.2%)	5 (12.8%)	0.043
Phlegm	6 (15.4%)	1 (2.6%)	0.009
Dyspnea	7 (17.9%)	4 (10.3%)	0.094
Wheezing	5 (12.8%)	3 (7.7%)	0.144
Chest tightness	4 (10.3%)	5 (12.8%)	0.345

Data are expressed as number and percentage of study subjects with certain variable. *Tested by chi-square test or Fisher's exact test where appropriate.

Prevalence of respiratory symptoms within the last 12 months was higher in welders with duration of workplace exposure more than 12 years than in welding workers with duration of workplace exposure less than 12 years with significant difference for phlegm and dyspnea (Table 3).

Table 3: Prevalence of respiratory symptoms within the last 12 months in welders with duration of workplace exposure more and less than 12 years.

Respiratory symptoms in the last 12 months	Exposed more than 12 years (n = 21)	Exposed less than 12 years (n = 18)	*P*-value*
Any respiratory symptom	12 (57.1%)	6 (33.3%)	0.081
Cough	7 (33.3%)	4 (22.2%)	0.092
Phlegm	5 (23.8%)	1 (5.6%)	0.014
Dyspnea	5 (23.8%)	2 (11.1%)	0.047
Wheezing	3 (16.6%)	2 (11.1%)	0.216
Chest tightness	2 (9.5%)	2 (11.1%)	0.387

Data are expressed as number and percentage of study subjects with certain variable. *Tested by chi-square test or Fisher's exact test where appropriate.

Prevalence of sensitization to common inhalant allergens was similar in both examined groups. Mite sensitization was detected as the most important individual common inhalant allergen among subjects with positive SPT in both groups (Table 4). Prevalence of sensitization to common inhalant allergens was also similar in the welders with duration of workplace exposure more and less than 12 years.

Table 4: Prevalence of sensitization to common inhalant allergens in examined groups.

Common inhalant allergen	Welders (n = 39)	Office workers (n = 39)	*P*-value*
Any common inhalant allergen	12 (31.6%)	11 (28.9%)	0.702
Birch	4 (10.4%)	4 (10.4%)	1.000
Grass mixed	6 (15.7%)	7 (18.4%)	0.612
Plantain	5 (13.2%)	4 (10.4%)	0.483
Fungi mixed	4 (10.4%)	5 (13.2%)	0.417
Dermatophagoides pteronyssinus	8 (21.1%)	7 (18.4%)	0.528
Dog hair	2 (5.2%)	2 (5.2%)	1.000
Cat fur	4 (10.4%)	3 (7.8%)	0.492
Feathers mixed	1 (2.6%)	2 (5.2%)	0.516

Data are expressed as number and percentage of study subjects with certain variable. *Tested by chi-square test or Fisher's exact test where appropriate.

Table 5: Mean values of spirometric parameters in examined groups.

Spirometric parameter	Welders (n = 38)	Office workers (n = 38)	*P*-value*
FVC (% pred)	87.6 ± 9.7	91.2 ± 8.9	0.119
FEV_1 (% pred)	83.4 ± 9.3	85.5 ± 7.9	0.189
FEV_1/FVC%	74.1 ± 4.8	75.4 ± 4.2	0.156
MEF_{50} (% pred)	57.4 ± 7.1	69.8 ± 6.0	0.008
MEF_{75} (% pred)	51.3 ± 5.9	65.9 ± 7.4	0.000
MEF_{25-75} (%pred)	68.4 ± 10.4	71.2 ± 11.8	0.063
BHR (%)	25.6	15.3	0.069**

Data are expressed as mean value with standard deviation. FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; MEF_{50}, MEF_{75}, MEF_{25-75}, maximal expiratory flow at 50%, 75%, and 25-75% of FVC, respectively; % pred, % of predicted value; BHR, bronchial hyperresponsiveness; *Tested by independent-sample *T*-test; ** Tested by chi-square test.

Mean values of spirometric parameters were lower in welders with statistical difference for MEF_{50} and MEF_{75}, whereas difference in the mean values of MEF_{25-75} just missed statistical significance (Table 5).

Table 6: Mean values of spirometric parameters in welders with duration of workplace exposure more and less than 12 years.

Spirometric parameter	Exposed more than 12 years (n = 21)	Exposed less than 12 years (n = 18)	*P*-value*
FVC (% pred)	86.2 ± 8.9	88.7 ± 6.5	0.127
FEV1 (% pred)	82.1 ± 7.1	84.8 ± 5.2	0.176
FEV_1/FVC%	73.6± 3.1	74.8 ± 4.0	0.194
MEF_{50} (% pred)	54.2 ± 6.3	60.9 ± 5.8	0.016
MEF_{75} (% pred)	45.6 ± 7.8	54.9 ± 8.1	0.000
MEF_{25-75} (%pred)	65.1 ± 12.2	70.7 ± 10.4	0.037

Data are expressed as mean value with standard deviation. FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 second; MEF_{50}, MEF_{75}, MEF_{25-75}, maximal expiratory flow at 50%, 75%, and 25-75% of FVC, respectively; % pred, % of predicted value; *Tested by independent-sample *T*-test.

Mean values of spirometric parameters were lower in welders exposed to welding gases and fumes more than 12 years than in those exposed less than 12 years with statistical significance for MEF_{50}, MEF_{75} and MEF_{25-75} (Table 6).

Prevalence of BHR was higher in welders but statistical significance was not reached (Table 5).

Table 7: Prevalence of BHR categories in examined groups.

BHR category	Welders (n = 39)	Office workers (n = 39)	*P*-value*
Moderate to severe BHR	/	/	/
Mild BHR	2 (5.1%)	2 (5.1%)	1.000
Borderline BHR	8 (20.5%)	3 (7.7%)	0.038

Data are expressed as number and percentage of study subjects with certain variable. *Tested by chi-square test or Fisher's exact test where appropriate.

In both examined groups there was no subject with moderate to severe BHR. Prevalence of mild BHR was similar in both examined groups, whereas prevalence of borderline BHR was significantly higher in welding workers (Table 7).

Table 8: Prevalence of BHR categories in welders with workplace exposure more and less than 12 years.

BHR category	Exposed more than 12 years (n = 21)	Exposed less than 12 years (n = 18)	*P*-value*
Moderate to severe BHR	/	/	/
Mild BHR	1 (4.8%)	1 (5.6%)	0.743
Borderline BHR	6 (28.6%)	2 (11.1%)	0.042

Data are expressed as number and percentage of study subjects with certain variable. *Tested by chi-square test or Fisher's exact test where appropriate.

Prevalence of mild BHR was similar in both subgroups of the welding workers. Prevalence of borderline BHR was significantly higher in welders with workplace exposure more than 12 years than in those exposed less than 12 years (Table 8).

Discussion

It is estimated that more than 1 million workers worldwide perform some type of welding as a part of their work duties [16]. Several studies performed worldwide showed increased risk for respiratory impairment in welding [17-20]. On the other hand, the results of the studies performed are difficult to compare because of differences in worker populations, industrial settings, welding techniques, duration of exposure, other occupational exposures besides welding fumes and gases, as well as of the kinds of protective measures taken [4]. The type of welding process, what the electrode is made of, base metals and filler metals, as well as paints and other coatings on the metals being welded are considered as the major determinants of the risk for adverse respiratory effects associated with welding [3, 4]. The main factor for the respiratory health of SS welders seems to be related to the great concentration of chromium and nickel contained in fumes coming from this type of welding [2, 3, 16]. Fumes generated during SS welding usually contain approximately 20% of chromium with 10% of nickel, whereas fumes from mild steel (MS) welding usually contain more than 80% iron with some manganese and nickel with the absence of chromium [4].

In the present study we compared prevalence of respiratory symptoms and allergic sensitization to common inhalant allergens, values of spirometric parameters, as well as prevalence of BHR between a group of males working as SS welders and a group of male office workers matched by age, duration of employment, and smoking status. We also evaluated the effect of duration of workplace exposure in welding to these parameters. The demographic characteristics were similar in both examined groups. In both groups there were a large proportion of current smokers that was similar to current smokers prevalence in adults documented in our previous studies [21-23]. We found a low prevalence of ex-smokers in both groups suggesting insufficient smoking cessation activities.

The prevalence of respiratory symptoms in the last 12 months was higher in welders than in office workers with statistical significance for cough and phlegm. Higher prevalence of respiratory symptoms in welders as compared with non-welder controls is reported in many studies that investigated adverse respiratory effects in welding [18, 19, 24]. Significantly higher prevalence of cough and sputum production, were reported by Sobaszek et al. [25] in a study that evaluated long-term respiratory effects of SS welding, which is similar to our findings. In a 9-year follow up study as a part of ECRHS II, Lillienberg et al. [26] reported significant association between welding in galvan zed material and SS and chronic bronchitis symptoms, as well as an increased prevalence of wheeze and welding in painted metal. We found higher prevalence of respiratory symptoms in the last 12 months in welders with duration of workplace exposure more than 12 years than in those exposed less than 12 years with significant difference for phlegm and dyspnea. Similarly, in a cross-sectional study including 62 current welders and 75 non-welders, Bradshaw et al. [27] reported significantly higher prevalence of chronic bronchitis symptoms in welders which was significantly associated with duration of exposure to welding fumes.

In the present study we found similar prevalence of allergic sensitization to common inhalant allergens in both examined groups. The pattern of allergic sensitization to common inhalant allergens in the examined groups was comparable to that we had previously observed among adults in Republic of Macedonia [28, 29]. Similar prevalence of allergic sensitization to common inhalant allergens, as well as its similar pattern was also found in our previous studies that investigated the effect of workplace exposure to different organic dusts and gases on atopic status of exposed workers [23, 30].

The effects of welding on lung function parameters are well documented in numerous studies, but the data of lung function investigations are not consistent which may be due to the factors mentioned above. In the present study we found lower values of all spirometric parameters in welders than in controls with significant difference for MEF_{50} and MEF_{75}, while the difference for MEF_{25-75} just missed statistical significance. Lung function investigations in never-smoking, high-exposed Danish welders performed by Lyngenbo et al. [31] showed significant difference between the welders and the control group in FVC, FEV_1, total lung capacity (TLC), peak expiratory flow rate (PEFR), MEF_{75}, diffusion capacity, and slope of the alveolar plateau. In a longitudinal study of welders and caulker-burners, Chinn et al. [32] reported decline of FVC, FEV_1, PEFR, and MEF_{50} over time indicating that the decrease was due equally to welding and smoking. On the other side, several studies showed little or no changes in lung function in welders. In the study of Sobaszek et al. [25] mentioned above, no difference was found between measured FEV_1, MEF_{50}, and MEF_{25-75} in SS welding workers and non-welder controls. Investigating short and long-term effects of occupational exposure in welders of zinc-coated mild steel, Marquart et al. [33] found no difference in lung function over a work shift, as well as borderline statistical significance between duration of exposure in years and decreased values of FEV_1 and FEV_1/FVC. Furthermore, McMillan & Pethybridge [34] reported no change in lung function of dockyard welders relative to controls, even though employed for an average of 33 years. We found lower mean values of spirometric parameters in welders with duration of workplace exposure more than 12 years than in welders occupationally exposed less than 12 years with significant difference for MEF_{50}, MEF_{75}, and MEF_{25-75}. In a study about the effects of welding fumes on lung function in non-smoking Pakistani welders who worked without the benefit of welding fume control ventilation and respiratory protective devices, Meo et al [35] reported significant reduction of FEV_1, FEV_1/FVC and PEFR with a dose-effect of years of welding on lung function.

Although BHR has been assessed in many epidemiological studies in adults and in children, its prevalence and severity have been evaluated in only few studies related to occupation [36-40]. In the present study we found higher BHR prevalence in welders than in controls but statistical significance was not achieved. Perfoming a 3-year survey that measured respiratory symptoms, spirometry, and metacholine reactivity in welders and non-welder controls, Beckett et al. [40] did not find significant difference in the BHR prevalence between examined groups, neither at baseline, nor during follow-up. Within our present study we assessed BHR using histamine as the bronchoconstrictor. Even though histamine and metacholine are not fully interchangeable, both agents provide concordant results [6]. Results similar to ours are presented by Ould-Kadi et al. [41] in a study assessing respiratory function and bronchial responsiveness among industrial workers exposed to different classes of occupational agents. They did not find significant difference in BHR prevalence evaluated by histamine challenge between welding workers and non-welder controls. We found significantly higher prevalence of borderline BHR in welders than in controls, as well as in welders with workplace exposure more than 12 years than in welders with workplace exposure less than 12 years. This difference may be due to the association of welding in stainless steel and chronic bronchitis indicated by Lillienberg et al. [26].

The present study must be interpreted within the context of its limitations. First, relatively small number of the subjects in the study groups may be a major limitation, and could have certain implications on the data obtained and its interpretation. Second, we did not perform SPT to workplace allergens, so we could not document relationship between sensitization to workplace allergens with respiratory symptoms and lung function parameters. Third, environmental measurements were not performed, so we could not document the effect of the type and the level of exposure on examined variables.

In conclusion, in a cross-sectional study aimed at assessment of adverse respiratory effects and immunological changes in welding workers we found higher prevalence of respiratory symptoms in the last 12 months with significant difference for cough and phlegm, similar prevalence of allergic sensitization to common inhalant allergens, significantly lower values of two parameters of forced expiratory flow (MEF_{50} and MEF_{75}), as well as higher prevalence of BHR in welders than in controls. Respiratory impairment was close related to the duration of workplace exposure. Our results confirm the need of regular medical examinations of welding workers in order to implement appropriate preventive measures regarding the risks of welding exposure.

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