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Respiratory symptoms and pulmonary function among welders working with aluminum, stainless steel and railroad tracks

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SJÖGREN B, ULFVARSON U. Respiratory symptoms and pulmonary function among welders working with aluminum, stainless steel and railroad tracks. *Scand J Work Environ Health* 11 (1985) 27–32. Sixty-four aluminum welders, 46 stainless steel welders, and 149 railroad track welders were investigated regarding respiratory symptoms and pulmonary function (forced vital capacity and forced expiratory volume in 1 s). Referents consisted of nonwelding industrial workers and railroad workers. All groups of welders showed a higher frequency of chronic bronchitis symptoms than their respective referents. Respiratory symptoms were related to ozone concentrations in welders working with aluminum. In stainless steel and railroad track welders respiratory symptoms were related to chromium exposure rather than to total particle exposure. The pulmonary function was not affected in any of the welding groups studied.

Key terms: chromium, chronic bronchitis.

Welding is a process of fusing metals together by melting. Electric-arc welding uses techniques to protect the melting metal from the oxidizing power of the air. In metal arc welding the melted metal is protected by material in the coating of the electrode, and in gas-shielded welding an inert gas acts as protection. Two different methods of gas-shielded welding are used. Metal inert-gas (MIG) welding uses a consumable electrode, and in tungsten inert-gas (TIG) welding a nonconsumable electrode of wolfram is used.

Welding generates particles and gases which are characteristic for the method used and the material welded. Gas-shielded welding of aluminum produces ultraviolet radiation, which causes oxygen in the air to form ozone (7). Recently a case of pulmonary fibrosis was reported for a worker who had welded aluminum for 17 years, mainly in confined spaces (28). Manual metal arc welding with coated electrodes on stainless steel generates particles of easily soluble hexavalent chromium (19, 25, 27). The major component of welding fumes from low-alloy steel is iron oxide (23).

The purpose of this study was to investigate respiratory symptoms in relation to concentrations of air contaminants and pulmonary function in different groups of welders as part of a comprehensive study of Swedish welders.

Subjects

The three different exposed populations were identified in two different ways.

Enterprises consuming welding material were traced in a Register of Enterprises held by the National Bureau of Statistics. Representatives from companies with some welding material consumption were interviewed about the number of welders, the material welded, and the method used, as well as the welding intensity for each welder. At the time of the study about 200 welders in the country worked mainly on aluminum with gas-shielded welding, and about 400 welders worked mainly on stainless steel with coated electrodes (11). Aluminum and stainless steel welders were included in the investigation if they had worked for at least one year with the method being studied and at least 3.5 h each workday and were present on the days of the examination. In the interview many welders stated less welding time than that estimated by the representatives of the companies. The welders worked in a geographic region extending from 600 km south to 300 km north of Stockholm.

One group of 64 welders working with gas-shielded welding (both MIG and TIG) on aluminum, agreed to participate in the study and none refused. The median exposure time of this group was 5 (range 1–24) years.

All 46 welders who worked with coated electrodes on stainless steel and who fulfilled the entrance criteria agreed to participate in the study. Their median exposure time was 15 (range 1–39) years.

At the time of the study 215 persons were welding railroad tracks for the Swedish State Railways. Welders working in remote areas of the country were excluded from the study for practical reasons. No

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specific restrictions as to welding time per day were applied to this group. One hundred and forty-nine welders accepted participation and none refused. The welding work consisted mainly of joining rails by mold welding and overlay welding of worn or damaged rails. Basic electrodes were used in both operations. The electrode used for overlay welding contained 3.2 % chromium. The median exposure time of these welders was 18 (range 5–41) years.

An aged-matched (within four years) referent was chosen for each aluminum and stainless steel welder. These referents were nonwelding industrial workers chosen from the same company or from the geographically nearest company. If possible the referents were also matched for smoking habits.

Referents for the railroad track welders were nonwelding railroad workers from about the same geographic areas as the welders. The number of

referents was 70, and they were neither individually matched for age nor for smoking habits.

All the welders and referents were males.

Methods

The welding fume samples were collected on cellulose ester membrane filters (Millipore filter AAWP, diameter 37 mm, mean pore size $0.8 \mu\text{m}$) with personal sampling pumps (MSA monitaire sampler pump, model G) with a calibrated flow. The filters were placed inside the welding helmet. Total particle welding fume amounts were measured gravimetrically. The sampling period was at least 4 h, and time-weighted average concentrations for the sampling period were calculated.

Total chromium amounts were analyzed with a particle-induced X-ray emission (PIXE) technique at the Department of Nuclear Physics, Institute of Technology, Lund. The detection limit was $0.1 \mu\text{g}/\text{m}^3$ (26), and the coefficient of variation was 10 % (14).

Ozone was measured by a chemiluminescence instrument inside the welding helmet. This instrument is practically specific for ozone, and the detection limit is about 0.001 ppm (26). These measurements were performed during at least two 15-min periods.

Ulfvarson (26) has thoroughly described all the methods used for the assessment of particles and gases in these studies, and all measurements were aimed to represent normal work conditions.

All the participants were interviewed in a standardized way. A modification of the British Medical Research Council's questionnaire on respiratory symptoms was used. Chronic bronchitis was defined as daily cough and production of phlegm for as much as three months each year. This definition is very close to that given by the World Health Organization (30).

Forced vital capacity (FVC) and forced expiratory volume in 1 s ($\text{FEV}_{1.0}$) were registered at least three times for each person with a vitalograph. The tests were performed with the subjects in the standing position and without a noseclip. The best value for each variable was used in the analysis, and all volumes were corrected to body temperature and pressure saturated with water vapor (BTPS). Regression equations were calculated in which age and height were independent variables and FVC and $\text{FEV}_{1.0}$ were dependent variables.

Two vitalographs were used during the study. At the end of the data collection one spirometer showed plus 0.1 l at the 5-l calibration and the other minus 0.1 l at the same volume.

Nonsmokers were defined as subjects who had never smoked or who had quit smoking more than two years ago. Subjects who stopped smoking less than two years ago were excluded.

Figure 1. Distribution of total particle concentration in different welding operations according to Ulfvarson (26). The percentages marked in the lower left-hand corner of the figure show the percentage of measurements represented by the column area in question. (The current occupational exposure limit for respirable particles is $5 \text{ mg}/\text{m}^3$.) (A = tungsten inert-gas welding of aluminum, B = metal inert-gas welding of aluminum, C = coated electrodes on stainless steel, D = tungsten inert-gas welding of stainless steel, E = coated electrodes in the overlaying of rails, F = coated electrodes in rail splicing).

Table 1. Reported chronic bronchitis among the subgroups of welders and their referents. Welders with exposure of less than 2 years were excluded.

Type of welding	Welders		Referents		Crude risk ratio
	Total number	Number with bronchitis	Total number	Number with bronchitis	
Gas-shielded welding on aluminum	59	4	64	2	2.2
Coated electrodes on stainless steel	44	4	46	2	2.1
Railroad track welding	149	7	70	1	3.3

The differences in the frequencies were tested by the chi-square test, and the differences in the means were tested by Student's t-test. The Mantel-Haenszel test was used for the analysis of stratification (20). The p-values refer to two-tailed tests. Statistical significance means that $p < 0.05$.

Exposure

Electric-arc welding generates fume in which the majority of the particles are smaller than $1 \mu\text{m}$ and thus respirable (2, 26). The distribution of the total particle concentrations for different welding operations without local exhaust ventilation is shown in figure 1.

The current Swedish occupational exposure limit for hexavalent chromium is $20 \mu\text{g}/\text{m}^3$. More than 80 % of the chromium concentrations exceeded that value when stainless steel was welded with coated electrodes.

The current Swedish 8-h occupational exposure limit for ozone is 0.1 ppm. Almost 50 % of the ozone concentrations exceeded that limit when MIG welding was performed on aluminum. The concentrations of oxides of nitrogen were typically below 5 ppm, regardless of the welding method.

The exposure conditions have been extensively analyzed and published by Ulfvarson (26).

Results

Chronic bronchitis

All the groups of welders reported higher frequencies of chronic bronchitis than their respective referents, but the differences were not statistically significant (table 1).

As smoking is strongly associated with chronic bronchitis, a stratification due to smoking was made (table 2). All the welders were included, as the number of welders with chronic bronchitis was very small in each subgroup. This analysis showed smoking to be a stronger determinant for chronic bronchitis than welding fume exposure.

Table 2. Reported chronic bronchitis among all the welders and their referents divided into smokers and nonsmokers. Welders with exposure of less than 2 years were excluded.^a

	Welders		Referents	
	Total number	Number with bronchitis	Total number	Number with bronchitis
Smokers	119	12	82	5
Nonsmokers	128	3	94	0

^a Crude risk ratio due to welding: 2.14 ($p = 0.12$); risk ratio after stratification for smoking: 2.08 ($p = 0.13$). Crude risk ratio due to smoking: 6.26 ($p < 0.001$); risk ratio after stratification for welding: 6.15 ($p < 0.001$).

Respiratory symptoms related to welding

All three groups of welders had significantly more respiratory symptoms (eg, cough, phlegm, or a sense of irritation) in connection with work than their respective reference group. In general these symptoms were of shorter duration than the symptoms included in the definition of chronic bronchitis.

Welders working with gas-shielded welding on aluminum had more respiratory symptoms at higher ozone concentrations than at lower concentrations (figure 2). A comparison between exposure category I and category II gave a p-value of 0.03.

Respiratory symptoms were more common at higher than at lower chromium concentrations among stainless steel, as well as among railroad track, welders (figures 3 & 4), but this tendency was not statistically significant.

Respiratory symptoms did not seem to show any relationship with the total particle concentrations of the three groups of welders.

Pulmonary function

As FVC and $\text{FEV}_{1.0}$ vary with age and height, all these variables are presented (table 3). There were no differences regarding FVC or $\text{FEV}_{1.0}$ between the three groups of welders and their respective reference groups. Neither did the subjects with long exposure periods have decreased pulmonary function variables.

Figure 2. Respiratory symptoms of the referents (R) and the groups of welders (working with gas-shielded welding of aluminum) with different levels of exposure to ozone and particles.

Discussion

Chronic bronchitis

Published reports on welders have explicitly or implicitly concerned electric-arc welding on low-alloyed steel, and they have shown an increased frequency of chronic bronchitis with risk ratios varying between 1.2 and 3.1 (1, 3, 4, 5, 8, 22). This study also showed somewhat increased frequencies of chronic bronchitis in all the subgroups of welders, close to the previously found risk ratios.

Smoking affected the frequency of chronic bronchitis more than welding. The risk ratio was within the earlier-reported range of 2–14 (10, 17, 21, 29).

Stainless steel welding with coated electrodes has previously been associated with asthma (16). The present study did not reveal obstructive disease among the exposed subjects, a finding which could be explained by selection through job exchange for welders with severe respiratory disorders.

Respiratory symptoms related to welding

The present study showed ozone rather than aluminum particles to be responsible for the respiratory symptoms among the aluminum welders, this finding is in accordance with the results of an experimental study (9) in which 0.35 ppm of ozone, but not

Figure 3. Respiratory symptoms of the referents (R) and the groups of welders (working with coated electrodes on stainless steel) with different levels of exposure to chromium and particles.

Figure 4. Respiratory symptoms of the referents (R) and the groups of railroad track welders with different levels of exposure to chromium and particles.

Table 3. Mean values for the age, height, forced vital capacity, and forced expiratory volume in 1 s of aluminum, stainless steel, and railroad track welders and their respective referents.

Group	Number	Age (years)	Height (cm)	Forced vital capacity (l)	Forced expiratory volume in 1 s (l/s)
All welders					
Aluminum welders	64	37.3	176.7	5.36	4.34
Referents	64	37.3	175.1	5.13	4.18
Stainless steel welders	46	45.7	175.0	5.00	3.97
Referents	46	45.7	174.9	4.98	3.96
Railroad track welders	148	46.6	175.7	5.12	4.07
Referents	70	46.8	175.2	5.17	4.09
Nonsmokers					
Aluminum welders	28	38.9	175.9	5.38	4.37
Referents	31	39.2	174.9	5.12	4.23
Stainless steel welders	21	46.2	175.3	4.97	3.97
Referents	25	47.1	174.6	4.96	4.01
Railroad track welders	82	46.3	175.4	5.15	4.17
Referents	38	47.6	174.6	5.26	4.23
Smokers					
Aluminum welders	34	35.7	177.5	5.33	4.34
Referents	33	35.5	175.3	5.14	4.13
Stainless steel welders	23	45.6	175.0	5.08	4.00
Referents	20	43.5	175.0	5.09	4.00
Railroad track welders	64	47.1	176.3	5.09	3.95
Referents	29	46.4	176.0	5.01	3.87

0.20 ppm, was associated with respiratory symptoms.

In a previous cross-sectional study of stainless steel and mild steel welders both groups had about the same frequency of respiratory symptoms (15); this finding agrees with the results of the present study.

For the stainless steel welders, as well as for the railroad track welders, respiratory symptoms seemed to be more correlated with chromium exposure than with total particle exposure. Most of the chromium is in a hexavalent state (19, 25, 27), and such compounds are known to be highly irritative (18).

Pulmonary function

As mentioned in the Methods section two vitalographs were used. One showed plus 0.1 l and the other minus 0.1 l at 5 l. Each vitalograph was used to investigate an equal number of exposed welders, as well as referents in a particular workshop, ie, an equal proportion of welders and referents were investigated with the same spirometer. Thus the internal validity was adequate for the study. Furthermore, the regression equations, in which FVC and FEV_{1.0} were calculated from height and age, were similar to previously reported equations (6).

In recent case reports pulmonary fibrosis and desquamative interstitial pneumonia have been discovered in two aluminum welders (12, 28). These cross-sectional data do not support any deterioration due to long-term exposure. The inherent selection weakness of a cross-sectional study must however be borne in mind.

The present study supports the findings of one published study showing no effect on pulmonary

function in stainless steel welders in a comparison with reference values (15).

The railroad track welders in this study did not exhibit any impairment of pulmonary function. Obstructive changes have been observed previously among shipyard welders (1, 13). These differences concerning pulmonary function might be explained by the fact that shipyard welders often work in semi-confined or confined spaces, contrary to railroad track welders, and therefore are exposed to higher concentrations of air contaminants. In railroad track welding 25–50 % of the measured total particle concentrations inside the welding helmet exceeded 5 mg/m³ (figure 1), and in Danish shipyards 50 % of the measurements in confined spaces were above 7 mg/m³ (24). However, the results from our study are in accordance with the spirometric results from welders working in engineering shops (3).

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