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Occupational Exposure to Manganese Among Welders: Association Between Airborne Manganese Concentration and Blood Manganese Levels

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Abstract

Background: Manganese (Mn) is an essential element for the human body, but it can cause adverse effects on the Central Nervous System at high doses. Exposure to manganese fumes during welding can harm welders' health.
Objectives: The current study aimed to measure manganese produced by shielded metal arc welding (SMAW) in the breathing zone air and blood of welders and investigate the relationship between manganese concentrations in air and blood.
Methods: In this descriptive-analytical cross-sectional study, 35 welders were enrolled as the exposed group and 40 office workers as the control group. Manganese concentration in air was measured according to NIOSH method 7301. Air and blood sample analyses were carried out by ICP-OES. Statistical analysis was performed with MINITAB 17. Data were analyzed using Pearson correlation coefficient, one-sample *t*-test, paired *t*-test, and logistic regression. The significance level was set at $P < 0.05$.
Result: The mean concentration of welding respirable particles and manganese fumes were 9.56 ± 1.67 and 0.45 ± 0.08 mg/m^3, three and 22 times the exposure limit recommended by ACGIH, respectively. Average manganese was significantly higher in the welders' blood (0.16 ± 0.02 μg/mL) than in the controls' blood (0.04 ± 0.002 μg/mL). There were strong and significant correlations between the welding respirable particles and manganese concentration in welders' breathing zone and blood manganese levels. Also, with each year of work experience, the manganese concentration in the welders' blood increased by 1.5%.
Conclusions: Welders are at risk of contamination with manganese. Manganese exposure reduction through more efficient ventilation systems, reducing welder's exposure time, staff training, and appropriate respiratory protection equipment should be applied to reduce manganese exposure among welders and prevent health complications.

Keywords: Welding, Manganese, Occupational Exposure, Biological Monitoring, Respirable Particles

1. Background

Welding is a common process for bonding metals by heat through an electric arc (1). The fumes produced in the welding process are hazardous for human health and contain particles created when gases are condensed after the sublimation of molten material (2). Iron oxide is the main chemical in the fume produced during welding, but there may also be other metals such as manganese, chromium, nickel, lead, copper, molybdenum, cobalt, cadmium, zinc, and aluminum in welding fumes (3). According to 2011 estimates, almost 11 million people worldwide worked as welders, and 110 million were exposed to welding fumes (4).

Studies about the hazardous effects of welding fumes have reported adverse respiratory effects such as airway irritation, decreased lung function, asthma, bronchitis, pneumoconiosis, and lung cancer (5). However, little information exists about the non-respiratory effects of welding fumes, particularly neurological effects (6). Manganese is an essential element in steel production that increases steel strength and prevents cracking (7). Although manganese is an essential element for the human body, at high doses, it can cause adverse effects on the central nervous system (CNS) (8) and behavioral-neurological disorders such as Parkinson's disease (9). According to Some studies, the manganese exposure threshold for the occurrence of subclinical neurological effects is 0.27 - 1.7 mg/m^3 (10, 11). Welding fumes containing manganese reduces heterogeneity in a magnetic field and increases brain proton rotation, resulting in shorter proton relaxation time. Cognitive, neurological disorders associated with manganese exposure occur more frequently in the cerebral cortex, particularly the anterior cingulate cortex (12).

The permissible exposure limit (PEL-Ceiling) recommended by the Occupational Safety and Health Administration for manganese in total inhalable dust is 5 mg/m^3 (13). The American Conference of Governmental Industrial Hygienists (ACGIH) has also determined the eight-hour Threshold Limit Value-Time-Weighted Average (TLV-TWA) for welding respirable particles and manganese as 3 and 0.02 mg/m^3, respectively (14). However, the National Institute for Occupational Safety and Health (NIOSH) has determined eight-hour TWA-TLV for manganese exposure as 1 mg/m^3 (15).

Biological monitoring is an efficient tool to assess occupational exposure and its risk factors. Moreover, biological monitoring can help prevent undesirable health effects (8). Based on studies, magnetic resonance imaging (MRI) can show manganese accumulation in the brain (16). However, MRI is not suitable for screening large populations due to its high cost. Blood and urine samples are the most common samples for monitoring human contamination with heavy metals. Nevertheless, manganese excreted in urine constitutes a small percentage of manganese absorbed in the body (17), making monitoring very difficult. However, as metals are transferred in the body by blood, blood samples can be used to measure manganese exposure (18). According to references, $\geq$ 4 $\mu g/L$ of manganese in the blood shows manganese contamination in humans, and the normal range is 1 - 4 $\mu g/L$ (19). Studies have shown that blood is a better medium for measuring manganese exposure than urine and hair (20). However, other studies have reported a weak correlation between manganese concentration in plasma and external exposure levels (21). There is still no agreement about the best biological sample for measuring manganese exposure.

Studies have shown that insufficient ventilation and lacked safety equipment put welders at risk of adverse health effects of manganese exposure in many welding workshops (22). Many welders in Iran, particularly Mazandaran province, are exposed to welding fumes. However, there are limited studies on this issue, especially concerning this type of welding and the use of electrodes. Also, studies have reported different results regarding the relationship between exposure to airborne manganese and high blood manganese in Iran (12, 19).

2. Objectives

The current study aimed to measure manganese in the respiratory zone air and blood of welders and investigate the relationship between manganese concentrations in air and blood.

3. Methods

3.1. Study Subjects

This descriptive-analytical cross-sectional study was conducted in a metal factory in Babol city in 2019. The inclusion criterion was having at least one year of work experience as a welder. People using certain drugs containing manganese, smokers, and alcohol users were excluded from the study. According to the results of a study by Hassani et al. (23) in which the mean difference of manganese in the blood of welders and controls was 6.51 ($\mu g/mL$) (pooled SD = 7.99), the minimum sample size needed was 24 people in each group. However, all 35 male welders who met the inclusion criteria were included to increase the power of the study. Also, 40 male administrative staff of the same factory were selected as the control group who were matched with samples in terms of work experience. All welders in this study were engaged in the same department and used the same materials for welding.

Participation in this study was voluntary. All participants signed informed consent forms. Participants were ensured that their information would remain confidential and be used only for research purposes. The Local Ethics Committee confirmed the study protocol with the code IR.MAZUMS.REC.1398.4955.

3.2. Work Description

All welders in this factory did shielded metal arc welding (SMAW) with electrodes E7018 and E6010 containing 0.5 to 0.9% manganese (24). The welders worked 44 hours per week and five hours a day on metal sheets containing 0.9 to 0.11% manganese to build boiler pots. Most exposed welders (91%) used a hatter man welding mask model EN 175 for protection.

3.3. Sampling Air

Air samples were taken by cellulose ester filters with a diameter of 37 mm, a pore size of 0.8 μm, and a flow rate of 2.5 L/min from the respiratory area of welders using an SKC sampling pump (model AirChek 3000 Deluxe). Before sampling, filters were placed in a desiccator for 24 h and dried and weighed by a sensitive scale with an accuracy of 1 μg

(model SARTORIUS, MES, made in Germany). Sampling constantly continued over a working shift for 20 to 480 min. To control for sampling and analysis errors, we used four control filters, and all steps, except for air sampling, were done for them. The welding respirable particles concentration were determined based on the weight method. The NIOSH method 7301 was used to determine manganese concentration in welding respirable particles (25).

3.4. Biological Monitoring and Preparation of Samples

Blood samples were collected from all participants at the end of their working shift using 5 cc syringes on the air sampling day. Sampling syringes and sample collection containers were free from heavy metal contamination. In this study, 1 mL of venous blood was taken from each person in the medical facility room of the company. Samples were poured into K2 anticoagulant tubes and kept at -20°C until analysis. Blood samples were then prepared according to Elligsen et al. (26), in which 1.5 mL of pure nitric acid was added to 1 mL of venous blood and exposed to a temperature of 95°C for one hour. After cooling, the samples were diluted to 10 mL.

To prepare air samples using NIOSH method 7301, we placed the samples in clean beakers. Then, 5 mL aqua regia ($1HNO_3$:3HCl) was added to the filter covered with watch glasses exposed to room temperature for 30 min. Samples were heated on a hotplate at 120°C until only 0.5 mL of the solution remained. Filter digestion was performed by adding 2 mL of aqua regia until a clear solution was obtained. Watch glasses were taken out and rinsed into the beaker with distilled water. The temperature was increased to 150°C, and the samples were taken to near dryness. In the last step, 3 mL of dilution acid was added to the solution and transferred to a 25-volume balloon.

3.5. Analysis

After the preparation, chemical analysis was carried out by inductively coupled plasma optical emission spectrometry (model PlasmaQuant PQ 9000, made in Germany) at the Laboratory of the Deputy of Health, Mazandaran University of Medical Sciences. Before sample analysis, standard manganese solutions (1000 mg/L) were prepared at specific concentrations and were injected into the device to obtain the calibration curve. Then, according to the standard method, the extracted and control samples were injected into the device, and the manganese concentration in the samples was determined. The results were compared with the permissible limits of ACGIH.

3.6. Statistical Analysis

The data were analyzed by MINITAB 17. The normality of data was checked by the Kolmogorov-Smirnov test. Descriptive statistics were used to summarize the demographic and occupational data of the participants. Data analysis was done using Pearson correlation coefficient, one-sample *t*-test, paired *t*-test, and logistic regression. The significance level was set at $P < 0.05$.

4. Results

This study enrolled 75 people, including 35 welders and 40 administrative staff (controls). The mean age of the exposed group was 34.42 $\pm$ 4.80 years, with a work experience of 12.12 $\pm$ 4.07 years. The mean age and work experience in the control group were 31.97 $\pm$ 4.53 and 11.85 $\pm$ 4.38 years, respectively. Work experience was not statistically different between the groups (Table 1). All participants were male.

The mean manganese levels measured in air and blood are shown in Table 2. Samples from the welders' respiratory area showed that the average exposure to welding respirable particles and manganese concentrations were 9.56 $\pm$ 1.67 mg/m^3 and 0.45 $\pm$ 0.08 mg/m^3, respectively. The average welders' blood manganese (0.16 $\pm$ 0.02 μg/mL) was significantly higher than the average administrative staff's blood manganese (0.04 $\pm$ 0.002 μg/mL) ($P < 0.001$) (Table 2).

Welding respirable particles and manganese concentrations are compared with the permissible limits in Table 3. Average manganese and respirable particles concentrations in welding stations were significantly higher than TLV-TWA permitted by ACGIH for manganese (0.02 mg/m^3) and airborne concentrations of respirable particles (3 mg/m^3) (Table 3).

Pearson correlation coefficients showed a significant linear relationship between welding respirable particles and manganese concentration in welders' respiratory air and blood manganese levels (Table 4).

Linear regression showed that work experience could predict welders' blood manganese concentrations (Table 5). The results showed that for each year increase in work experience, the blood manganese concentration of welders increased by 0.015 (1.5%).

5. Discussion

Welding is one of the most common industrial activities. It is estimated that welders make up more than one percent of the workforce in each country (27). Exposure to welding fumes is one of the most harmful occupational risk factors (28). In this study, manganese constituted 0.2 to 8% of welding respirable particles. Most of these fumes are released in the form of particles, which pollute the

Table 1. Demographic Information of Study Groups Compared by *t*-test

Variables	Welders	Controls	P Value
Age (y) [a]	34.42 ± 4.80	31.97 ± 4.53	0.01
Min	23	24	
Max	45	43	
Q2 (Q1 - Q3)	35 (31 - 38)	32 (27.5 - 35)	
Work experience (y) [a]	12.12 ± 4.07	11.85 ± 4.38	0.48
Min	3	1	
Max	20	22	
Q2 (Q1 - Q3)	12 (10 - 15.7)	10.5 (10 - 15.7)	

[a] Values are expressed as mean ± SD.

Table 2. Manganese Concentration in Air and Blood Compared by *t*-test

Group	n	Sample	Mean ± SD	Range	P Value
Welders	35	Air (mg/m^3)	0.45 ± 0.08	0.00 - 1.64	-
		Blood (μg/mL)	0.16 ± 0.02	0.03 - 0.40	
Controls	40	Blood (μg/mL)	0.04 ± 0.00	0.03 - 0.11	P < 0.001

Table 3. Comparison of Welding Respirable Particles and Manganese Concentrations with Permissible Limits in Welders (One-Sample *t*-test)

	Mean Concentration (CI 95%) (mg/m^3)	TLV-TWA (mg/m^3)	P Value
Welding respirable particles	9.56 (6.1 - 12.9)	3	< 0.001
Manganese	0.45 (0.29 - 0.61)	0.02	< 0.001

Table 4. Correlation Between Manganese in Welding Respirable Particles and Manganese in Blood and Breathing Air Samples of Welders

	Welding respirable particles (mg/m^3)	Mn Blood
Mn in welder's blood samples (μg/mL)		
Pearson correlation	0.94	-
P value	< 0.001	-
Mn in welders' breathing zone (mg/m^3)		
Pearson correlation	0.96	0.95
P value	< 0.001	< 0.001

Table 5. Effect of Age and Work Experience on Manganese Concentration in Blood Samples of Welders in Linear Regression [a]

	Coef	SE Coef	T Value	P Value	R-sq (adj)
Constant	-0.178	0.14	-1.26	0.21	31.76%
Experience	0.01542	0.00609	2.53	0.01	
Age	0.00470	0.00512	0.92	0.36	

[a] Regression Equation, Mn blood = -0.178 + 0.01542 experience + 0.00470 Age

working environment and harm human organs and tissues, including the eyes, respiratory system, and central nervous system (29).

This study showed that the average concentrations of welding respirable particles and manganese were three and 22 times the TLV-TWA recommended by ACGIH, respectively. These welders worked in a closed saloon without efficient ventilation and respiratory protection equipment.

In a study conducted by Harris et al. to assess exposure to manganese fume among SMAW welders working in a closed space, with 2,000 ft^3/min dilution ventilation, manganese concentrations in air samples taken from five locations close to the welder's body were within 75% of the current threshold limit value for total manganese and were five times greater than the proposed respirable manganese TLV (30). Pesch et al. investigated exposure to inhalable and respirable fumes in 241 welders from 25 German companies and reported that manganese concentrations in respiratory samples were higher than the permissible limit in 65% of the cases and were significantly higher when local exhaust ventilation (LEV) was inefficient, or welding was performed in confined spaces (31). Insley et al. showed that welders and metal workers working at a metal product fabrication facility in Western Pennsylvania were exposed to manganese and iron oxide levels significantly higher than the permissible limits (32). Besides, a study conducted by Hassani et al. showed that manganese exposure at a SMAW welding industry in Tehran was 0.023 ± 0.012 mg/m^3, which is above the current TLV-TWA permitted by ACGIH for manganese (0.02 mg/m^3) (23). The difference in findings can be justified by different working conditions and alloys used (26).

Previous studies have reported the adverse health effects of exposure to welding fumes that contain significant manganese levels (33, 34). It seems that although manganese constitutes a low percentage of the electrode alloys used in welding, welders are exposed to fumes that contain manganese beyond the permissible limits. Another reason for the high concentration of manganese in the respiratory area of welders is their inappropriate working posture. In professions such as welding, for better sight, access, or speed, workers might take inappropriate postures and get too close to the welding spot. Also, many welders work in saloons with inappropriate and inefficient ventilation systems.

The current study found a significant and robust correlation between breathing zone manganese concentrations and blood manganese concentrations in welders, meaning that increasing exposure to welding fumes in the breathing zone increases blood manganese levels. Also, the blood manganese concentration was significantly higher in welders than in controls.

Stanislawska et al. conducted a study on 67 welders and showed a direct and positive relationship between manganese concentration in the breathing zone and blood manganese levels (35). Also, Mehrifar et al. showed a moderate and significant correlation between airborne manganese concentration and blood manganese concentration, which is consistent with the current study results (12). On the other hand, Mirmohammadi et al. (19), Ellingsen et al. (26), and Halatek et al. (36) showed a poor correlation between manganese concentration in air and blood manganese levels in welders. It appears that the difference in the results is due to different sampling times in studies. The current study indicated that the blood manganese concentration of welders had a significant relationship with the work experience of welders. However, based on some studies, the blood manganese level only shows recent exposure and is unreliable for determining prolonged exposure (37, 38).

The results of previous studies about the best biological sample for measuring manganese contamination in humans are contradictory, and there is no consensus regarding the best biological indicator of exposure to manganese. Therefore, more data and quantitative/qualitative studies are needed to determine the best biological sample. Previous studies showed that blood and urine manganese concentrations were significantly higher in exposed welders than in controls (38-40). Baker et al. showed that 30 days following exposure to welding fumes, the blood manganese concentration of welders increased by 0.57 mg/mL with a daily increase in manganese in respiratory air by 1 mg/m^3 (41). In a study by Li et al., the blood manganese concentration was 4.3 times higher in welders than in controls. Also, the results showed that even exposure to lower concentrations of manganese over a long period would lead to increased manganese concentration in the blood (42). Hoet et al. reported that the blood manganese concentration was significantly higher in welders than in the control group, and it increased with an increase in exposure period (43). Furthermore, in a study by Ellingsen et al., the mean concentration of manganese in the blood was about 25% higher in welders than in controls, and blood manganese concentrations increased significantly with increased exposure (26). Abdullahi and Sani reported that exposure to welding fumes resulted in noticeable toxicity symptoms and increased blood manganese levels (44). According to these studies and the current study, blood samples may be appropriate to measure exposure to manganese in humans.

However, urine and hair have also been suitable samples to measure occupational and environmental exposure to manganese (40). Some studies indicated that hair and nail could be used as biomarkers of manganese exposure (45). However, Balachandran et al.'s study on hair as a manganese exposure biomarker revealed no significant relationship between manganese exposure and hair manganese concentration (46).

The researchers think that blood manganese is a more reliable biological marker than urine or hair to investigate exposure to manganese in humans (38, 47). However, Zheng and Crossgrove stated that blood manganese and urine could only show recent exposure to manganese (several hours to several days after exposure), and therefore they cannot be used to investigate long-term exposure to manganese (48). However, blood samples can provide important information about the relationship between exposure and effective biological dose (49).

A limitation of this study was the lack of information about the amount of manganese in the workers' diet. However, in a similar study, Laohaudomchok et al. reported that manganese absorbed from food in welders working at a local boilermaker union in Massachusetts was not considerable and did not increase the internal dose of manganese considerably (50). Another limitation of our study was that although this factory had a general ventilation system, we did not have quantitative information about the efficiency of the ventilation system.

5.1. Conclusions

Welders in this study were exposed to high manganese concentrations, as shown by high concentrations of manganese in their blood samples. To prevent health complications among welders, we suggest manganese exposure reduction through more efficient ventilation systems, reducing welder's exposure time, staff training, and appropriate respiratory protection equipment in this industry.

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Footnotes

Authors' Contribution: SR and MM conceived the idea and carried out the literature search and screening of studies; SR collected the data; SR and EB drafted the methodology; NK and JY-C analyzed the data; SR, MM, and EB led the writing process; NK, MM, SR, EB, and JY-C provided critical feedback. All authors reviewed the final manuscript and approved it for submission.

Conflict of Interests: The authors certify that they have no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.

Data Reproducibility: The data presented in this study are openly available in one of the repositories or will be available on request from the corresponding author by this journal representative at any time during submission or after publication. Otherwise, all consequences of possible withdrawal or future retraction will be with the corresponding author.

Ethical Approval: The authors have appropriately managed ethical issues, and the Ethics Committee of Mazandaran University of Medical Sciences has approved this study (IR.MAZUMS.REC.1398.4955).

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Informed Consent: All participants were informed of the purpose of this study and were ensured that their information would remain confidential and be used only for research purposes.

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