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Original Article

Occupational Exposure to Lead Fume Among Automobile Welders

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Abstract
Background and aims: Lead is one of the most dangerous toxic metals in the world. Therefore, this study aimed to investigate and assess the health risks of welders' occupational exposure to lead fumes.
Methods: A cross-sectional, descriptive-analytic study was conducted on 47 automobile welders. In this study, sampling and analysis of air lead concentration (ALC) were performed using the NIOSH 7082 standard and flame atomic absorption spectrophotometer. Then, the blood lead concentration (BLC) was measured using the NIOSH 8003 method via graphite furnace atomic absorption spectrophotometer. Additionally, the health risk assessment of people was conducted using the Environmental Protection Agency (EPA) method.
Results: Among the workers, 12.8% were smokers, and 66% used appropriate personal protective equipment (PPE). The average ALC and BLC of automobile welders were equal to 0.0458 ± 0.0296 mg/m3 and 9.89 ± 7.32 µg/dL, respectively. Although the Pearson coefficient showed a positive correlation between ALCs and BLCs, this correlation was not statistically significant ($P = 0.38$, $r = 0.18$). The value of chronic daily intake (CDI) and lifetime cancer risk (LCR) for lead fume exposure was 74×10^{-5} and 31×10^{-6}, respectively.
Conclusion: This study found higher average BLC levels in smokers, those who did not use PPE and in individuals over 30 years of age compared to those under 30 years. The mean BLC and ALC were consistent with the American Conference of Governmental Industrial Hygienists (ACGIH) standards, and the carcinogenic risk of exposure to lead fume was within the possible risk range.
Keywords: Health risk assessment, Welders, Lead fumes, NIOSH 7082, EPA method

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Introduction

Lead is a ubiquitous toxic metal with several valuable properties such as high density, ductility, high malleability, resistance to corrosion, low melting point, and recyclability. Lead is extensively used in industries and household appliances, including automobiles, soldering, welding, lead-acid batteries, plastics, paints, fuel, ceramics, and food storage cans.[1] Lead is non-biodegradable and remains persistent in the environment.[2,3] Although lead poisoning was recognized as early as 370 BC, it remains a critical growing occupational and environmental health concern.[2] Lead enters the body mainly through inhalation, ingestion, and skin. Inorganic lead exerts a wide range of adverse effects on humans even at low blood lead concentrations (BLCs), with no safety threshold.[3] The respiratory and gastrointestinal tracts are the main routes of inorganic lead absorption. Hence, workers' exposure to lead mainly occurs through the respiratory tract, with approximately 40% of inhaled lead absorbed into the blood plasma. The circulating lead binds to erythrocytes for about 30 days and distributes to several organs such as the kidneys, liver, brain, bones, and teeth.[4] After exposure, lead's half-life in blood is about 30 days, but it remains in bones for 10-20 years, so BLC could be a reliable indicator of recent lead exposure.[5]

Welding is the process of bonding two or more metals by applying heat. Globally, about 11 million people work as welders, and about 110 million people are continuously exposed to various welding fumes released during the welding process at work. These welding fumes contain metal aerosols such as lead, iron, copper, nickel, magnesium, zinc, cobalt, cadmium, and titanium.[6] Lead intoxication can be either acute or chronic. Chronic lead exposure may have deleterious effects on the nervous, renal, hematopoietic, gastrointestinal, reproductive, cardiovascular, and immune systems and can also cause behavioral dysfunctions.[7] Generally, these adverse effects of lead in the body are associated with systemic inflammation, cellular oxidative stress, suppression of antioxidant enzymes, impaired cellular functions, disrupted signaling cascades, and cell death.[8] Clinical manifestations of lea toxicity include dizziness, anxiety, dementia, muscle weakness, anemia, abdominal colic, constipation, loss of appetite, myalgia, encephalopathy, seizure, and even coma. Additionally, characteristic features are Burton's line on the gums, wrist drop, and basophilic stippling, which are not necessarily observed in every case of lead intoxication.[9] In addition, limited evidence suggests that inorganic lead compounds have carcinogenic effects on the lungs and the stomach of the exposed workers.[1]

Moreover, to achieve health goals and protect the workforce, it is necessary to examine individuals' exposure to chemicals and their associated risks.[10] To make decisions regarding effective control and protective measures for employees against the adverse chemical effects, it is necessary to precisely assess the health risks associated with exposure to these substances.[11] The risk assessment process is the crucial and leading solution for assessing risks associated with occupational and environmental chemical substance exposure.[12] Health risk assessment helps determine risk levels, enabling us to make informed decisions about necessary protective actions.[13] When conducting a risk assessment, time and resources can be well spent on less critical risks, while significant risks may be overlooked.[11]

Although comprehensive research has been conducted in the welding industry in Iran, there is a lack of studies focusing on welders in Birjand. As the welders are continuously exposed to fumes, the current study aimed to investigate the breathing air lead concentrations (ALCs) and BLCs of automobile welders in Birjand, using the Environmental Protection Agency (EPA) method for health risk assessment. Hence, the results can provide valuable information for assessing occupational health hazards.

Materials and Methods

Subjects

This cross-sectional, descriptive-analytic study investigated 47 automobile welders in Birjand (the capital of southern Khorasan province in Iran, from September 2018 to March 2019. The study mainly aimed to estimate ALCs and BLCs of automobile welders. Using the Cochran formula, a total sample size of 47 welders was calculated with an error margin of 5%. Inclusion criteria included male automobile welders with at least one year of welding experience and 8 hours of daily exposure. Data collected included environmental factors such as the presence of appropriate ventilation in the workplace and the availability of personal protective equipment (PPE), as well as demographic data (e.g., age, work experience, cigarette smoking, and PPE use with maximum privacy).

Personal Sampling and Measurement of Air Lead Concentrations

Air sampling was performed from one site of each two welders' sites. Personal air sampling was also used to assess exposure rates. According to the American Conference of Governmental Industrial Hygienists (ACGIH) standards,[14] the occupational exposure limit of lead in the breathing zone is 0.05 mg/m^3.

The National Institute for Occupational Safety and Health (NIOSH) has developed methods for measuring airborne lead. This study used method number 7082 of NIOSH for air sampling [15]. According to this method, a Mixed Cellulose Ester filter (37 mm, 0.9 µm pore size) was placed inside a filter holder and connected by flexible pipes to a personal air sampling pump (224-44MTX, SKC, US) with a flow rate of 2 L/min, calibrated with a digital calibrator (200-510M, UK). The filter holder was attached to the welders' collar (breathing zone). Notably, to cover the entire work shift of each welder, three samples were used at 2.5-hour intervals. Samples were transferred to the laboratory at the end of the shift and analyzed using a flame atomic absorption spectrophotometer (Varian AA240, Australia).[16] Then, 76 control samples were selected to eliminate possible error rates during sampling or transferring. Control samples were opened and closed in the sampling environment before being transferred to the laboratory as study samples. After placing filters in clean beakers, samples were digested with 1 mL of 30% hydrogen peroxide and 3 mL of concentrated nitric acid, then covered with a watch glass. Afterwards, they were heated to 140°C until only 0.5 mL of liquid was left. This step was repeated using 1 mL of 30% H2O2 and 2 mL of concentrated HNO3. The samples were then entirely dried by evaporation, and 5 mL of 10% HNO3 was used to rinse the watch glass and beaker walls. The residue materials were then dissolved in 1 mL of concentrated HNO3, transferred to a 10-mL volumetric flask, and diluted to volume using distilled water.

Before sample preparation, working standards ranging from 0.10 to 20 µg/mL in 10% HNO3 were generated, examined, and used to create a calibration graph. Due to the difference between the working environment conditions and standard conditions (25 °C and 760 mm Hg), temperature and humidity corrections were applied to the sampled air. Then, the results were compared with the occupational exposure limit for lead. For the ALC, the limit of detection (LOD) was 0.17 µg/m^3.[17]

Measurement of Blood Lead Concentration

Initially, 8 mL of the peripheral blood samples were collected in vacuum plastic tubes containing heparin, immediately transferred to the laboratory, and kept at -80°C until the testing time. An ammonium pyrrolidine dithiocarbamate (APDC)-surfactant solution was added to 2 mL of deionized water (blank) and approximately 2 mL of the blood sample. Then, they were combined in a vortex for 20 seconds. Subsequently, 2 mL of water-saturated methyl isobutyl ketone was added, vortexed for two minutes, centrifuged for ten minutes at 2000 rpm, and examined within two hours of extraction. BLCs were measured using a graphite furnace atomic absorption spectrophotometer (4-alpha, UK) at a wavelength of 283.3 nm. The LOD for BLC was 1.0 µg/dL. All BLCs were determined according to NIOSH Method Number 8003.[18] According to the ACGIH standards, the occupational exposure limit for blood lead was 20 µg/dL.[14]

ALCs and BLCs were measured at the Research Laboratory of Birjand University of Medical Sciences. Finally, the results of the blood and air samples were compared with the ACGIH standards, and the association between demographic variables and BLCs was investigated.

Health Risk Assessment Based on the Environmental Protection Agency Method

The International Agency for Research on Cancer (IARC) has classified inorganic lead compounds as probably carcinogenic to humans (Group A2). Therefore, this study used the US EPA's lifetime cancer risk (LCR) model to calculate the cancer risk of inorganic lead based on the measured lead concentration. The incremental lifetime cancer risk (ILCR) indicates the likelihood of increased cancer incidence from specific exposures.[19] LCR was calculated according to equation 1 from the product of the slope factor (SF) and chronic daily intake (CDI) 19.

$$LCR = CDI \times SF \tag{1}$$

The SF is an acceptable range within which there is a probability of creating a response to consuming one unit of a chemical substance in a lifetime, and its unit is kg per day per mg.[20] CDI represents exposure to a mass of substance per unit of body weight per unit of time over a relatively long period. CDI was calculated in mg/kg per day based on equation 2.[21]

$$CDI = \frac{(C \times IR \times ED \times EF \times LF)}{(BW \times ALT \times NY)} \tag{2}$$

where C is the average pollutant concentration in milligrams per cubic meter, IR is the breathing rate in cubic meters per hour, ED represents the duration of exposure in hours per week, EF depicts the exposure frequency in weeks per year, LF is the person's history in years, BW indicates body weight in kilograms, ALT is the average lifespan of a person, and NY denotes the number of days in a year.

In this study, information related to the person's history, duration of exposure, and frequency of exposure was collected through a questionnaire for each participant. The values for IR, average body weight, average lifespan, and the number of days in a year were considered 0.875 m^3/h,[22] 70 kg, 70 years, and 365 days, respectively.[21] This study recommended that the slope factor for lead pollutants be 0.042 mg/kg daily. The World Health Organization (WHO) has accepted the LCR in the range between 10^{-5} to 10^{-6} and less than this value.[20,23]. According to previous studies, an LCR value greater than 10^{-4} is considered a definite risk, an LCR between 10^{-4} to 10^{-5} is a probable risk, and an LCR between 10^{-5} to 10^{-6} is considered a possible risk.[24]

Statistical Analysis

Data analysis was conducted using SPSS software version 18. Due to the normal distribution of lead levels, an independent t-test was used, with an α level set at 0.05 for significance. Descriptive statistical tests were performed to evaluate quantitative variables, mean, and standard deviation. The results were expressed as mean ± standard deviation, and a significance threshold was considered less than 0.05.

Results

Environmental and Personal Demographic Information

The data for 47 welders in Birjand were collected from September 2018 to March 2019. The welders' mean age was 32.6 ± 8.8 years (range: 17 to 39 years), with a mean welding experience of 11.1 ± 7.6 years (range: 1 to 40 years). Among them, 12.8% were cigarette smokers, and 66% used PPE (Table 1). Due to similar ventilation conditions, ventilation was not considered a variable for BLC evaluation as there was no local ventilation in any workplace. However, the general ventilation was uniform and was provided through fan and natural ventilation.

Lead Concentration in the Air and Blood Samples

Air samples taken from 26 welding workers indicated a maximum ALC of 0.115 mg/m^3, with a mean of 0.0458 ± 0.0296 mg/m^3. Blood samples displayed a

Table 1. Welders' Environmental and Individual Demographic Information

Variable	Frequency	Percent
Age (y)		
Minimum	17	-
Maximum	39	-
Mean	32.6 ± 8.8	-
Welding experience (y)		
Minimum	1	-
Maximum	40	-
Mean	11.1 ± 7.6	-
Ventilation		
Appropriate	47	100
Inappropriate	0	0
Cigarette smoking		
Yes	6	12.8
No	41	87.2
Using PPE		
Yes	31	66
No	16	34

Note. PPE: Personal protective equipment.

Table 2. Lead Concentration in the Welders' Air and Blood Samples

Variable	Frequency	Minimum	Maximum	Mean	Median	SD
ALC (mg/m^3)	26	0	0.115	0.0458	0.041	0.0296
BLC (µg/dL)	47	0	28.89	9.89	9.33	7.32

Note. ALC: Air lead concentration; BLC: Blood lead concentration; SD: Standard deviation.

maximum BLC of 28.89 µg/dL, with a mean of 9.89 ± 7.32 µg/dL (Table 2). Moreover, Pearson's correlation coefficient (r) showed a positive correlation between ALCs and BLCs (r = 0.18), but this correlation was not statistically significant (P = 0.38).

Relationship Between Demographic Variables and Blood Lead Concentration

Table 3 presents the relationship between demographic variables and the BLCs. The results indicated no significant difference among the welders concerning PPE use, cigarette smoking, and age; however, the mean BLC was higher in cigarette smokers compared to those who did not use PPE. Additionally, the mean BLC in welders older than 30 was higher than those 30 years or less.

Comparison of Air Lead Concentrations and Blood Lead BLCs With the Standards of the American Conference of Governmental Industrial Hygienists Standards

As shown in Table 4, ALCs complied with ACGIH standards, while the BLCs of welders were significantly lower than ACGIH standards (P < 0.001).

Results of Health Risk Assessment

The results showed that the average concentration of lead measured in the air is 0.450 mg/m^3. Other information required to calculate the CDI of lead and, subsequently, the amount of LCR for individuals is provided in Table 5. According to Table 5, the CDI value is 74×10^{-5} mg/kg/d. Also, the incremental LCR for lead fume in welding is 31×10^{-6}. Therefore, according to the EPA method, the carcinogenic risk of exposure to lead fume in car welders is within the possible risk range.

Discussion

Occupational exposure to toxic metals is a global concern for workers in polluting industries in the industrial hygiene field.[25] The fields around the welders (breathing zone) contain contaminants produced during welding operations.[26] Lead is one of these pollutants, with 40% of inhaled lead being absorbed into blood circulation, which is the main route of inorganic lead absorption.[4] The present study investigated the ALCs and BLCs of automobile welders in Birjand. Based on the results, the mean BLC and the mean ALC of automobile welders were significantly lower than the permissible limit recommended by ACGIH. Moreover, the Pearson correlation coefficient demonstrated a positive correlation (r = 0.18) between ALCs and BLCs. Ono reported a significant correlation between ALC and BLC among workers occupationally exposed to lead-containing aerosols.[27]

Table 3. Comparison of the Mean BLCs of Welders in Terms of Demographic Variables

Variable	Frequency	Mean ± SD	Independent t-test
PPE use			
Yes	31	0.0968 ± 0.075	t = 0.28 P = 0.78
No	16	0.1031 ± 0.071	
Cigarette smoking			
Yes	6	0.1282 ± 0.082	t = 1.05 P = 0.3
No	41	0.0946 ± 0.072	
Age (y)			
≤ 30	22	0.0907 ± 0.078	t = 0.72 P = 0.48
> 30	25	0.1061 ± 0.069	

Note. BLC: Blood lead concentration; SD: Standard deviation; PPE: Personal protective equipment.

Table 4. Comparison of ALCs and BLCs With the Standards of the ACGIH

Variable	Frequency	Mean ± SD	One-Sample t-test
ALC (mg/m^3)	26	0.0458 ± 0.0296	t = 0.72 P = 0.48
BLC (µg/dL)	47	9.89 ± 7.32	t = 6.46 P < 0.001

Note. ALC: Air lead concentration; BLC: Blood lead concentration; ACGIH: American Conference of Governmental Industrial Hygienists; SD: Standard deviation.

In this study, air sampling was performed at 26 sites. The maximum ALC was 0.115 mg/m^3, and the mean ALC was 0.0458 ± 0.0296 mg/m^3, which was lower than the permissible limit (0.05 mg/m^3) based on the ACGIH standards. A cross-sectional study was done by Odongo et al to investigate the influence of exposure to airborne lead on BLCs among 20 automobile repair artisans in Kenya.[28] Their findings showed that the mean ALC of workers is 22.55 ± 5.05 µg/m^3, which was lower than the permissible limit, consistent with our results. Conversely, Ithnin et al conducted a cross-sectional study to assess the effects of exposure to welding fumes on the lung functionality tests of 30 welders in Malaysia,[29] indicating that the mean ALC of workers' breathing zone was 2.752 mg/m^3, higher than the permissible limit, which is inconsistent with the present study. This disparity might be due to differences in the type of equipment used and the ventilation conditions.

In the present study, the maximum BLC was 28.89 µg/dL, and the mean BLC of 47 welders was 9.89 ± 7.32 µg/dL. According to the ACGIH standards, the mean BLC was significantly lower than the permissible limit (20 µg/dL). In the same vein, Goyal et al measured the blood concentration of lead and cadmium among 207 individuals in Jodhpur, India[30] and found that the mean BLC of welders is 7.97 ± 1.92 µg/dL, while the non-exposed population had a mean BLC of 1.09 ± .073 µg/dL. This difference was

Table 5. Values of Parameters Used in Risk Assessment

Exposure Parameter	Value	Unit
C	0.045	mg/m^3
IR	0.875	m3/h
ED	40	H/wk
EF	52	Wk/y
LF	11.10	year
BW	70	kg
ATL	70	year
NY	250	day
CDI	74×10^{-5}	mg/kg/d
LCR	31×10^{-6}	-

Note. C: Concentration; IR: Inhale rate; ED: Exposure duration; EF: Exposure frequency; LF: Person's history in years; BW: Body weight; ALT: Average lifetime; NY: Number of days in a year; CDI: Chronic daily intake; LCR: Lifetime cancer risk.

statistically significant even though the reported BLC was lower than the permissible limit recommended by ACGIH.[14] Moreover, the findings of a study by Shriadeh et al[31] indicated a significantly higher BLC in automobile workers compared to controls in Jordan. Based on their results, the BLC of automobile welders was 14.5±1.4 µg/dL, which was lower than the permissible limit. Shriadeh et al[31] concluded that the mean BLC among welders was 460.28 ± 93.65 µg/L which was significantly higher than the permissible limit.

Additionally, Mirsalimi et al conducted a cross-sectional, descriptive-analytic study to measure the BLC of 46 workers employed in the lead and zinc mine in Isfahan province.[32] Another cross-sectional study by Ahmad et al[33] investigated the BLC and health problems related to lead intoxication among workers in a lead-acid battery factory in Bangladesh and showed that BLCs were high among workers, with a mean BLC of 65.25±26.66 µg/dL. These results are not consistent with our research, probably due to welders' exposure to other sources of lead. Furthermore, factors such as exposure to leaded paints, coal combustion, and other lead-containing chemicals, improper use of PPE, opium addiction, air pollution, using traditional medicine, and type of diet can elevate BLCs.[34]

Moreover, some workers do not adhere to hygienic principles, increasing the risk of overexposure to lead. These workers often do not use masks, goggles, gloves, and aprons and may eat food without washing their hands or smoke in their workplaces, so this condition and neglecting hygienic principles would expose them to lead through ingestion, inhalation, and skin contact.[35]

Elevated BLCs in some welders participating in our study may be related to groundwater and food contamination with lead in Birjand.[36] In this regard, Mansouri et al[37] reported that lead concentrations in Birjand's groundwater were 0.023 mg/L, which was higher than the national and international guidelines. Further, a study by Zeinali et al[38] evaluated heavy metal concentrations in the meat and other edible organs of cows and sheep in Birjand, finding that all samples were contaminated with lead, as well as other heavy metals. Moreover, another study reported lead contamination in all edible organs of chickens in Birjand.[39]

It is widely believed that tobacco products contain lead, which can be easily transferred to the body via cigarette smoking, leading to higher BLCs n smokers than in non-smokers.[40] In the present study, the mean BLC of cigarette smokers was higher than that of other welders, but this difference was not statistically significant. Shakeri et al[41] conducted a study to compare levels of different heavy metals between smokers and non-smokers in Birjand and found no significant difference between the mean BLC of the two groups. In line with our study, Ono found no significant difference between BLC in smokers and non-smoker workers in Japan.[27] Likewise, a study conducted in Tunisia on battery manufacturing workers showed no significant difference between the BLC of cigarette-smoking and non-smoking workers, suggesting that the close association between smoking habit and BLC in some studies maybe influenced by some confounding factors.[42] The effects of smoking habit on BLC need to be more considered in future studies.

Older people's exposure to lead is longer, so they are expected to have higher BLCs.[43] In the present study, the BLC of welders over 30 was higher than that of welders under 30, though this was not statistically significant. A study by Singh et al[44] evaluated the levels of heavy metals in occupationally exposed workers in India, indicating higher BLCs in older workers. Similar findings were observed in another study conducted on battery factory workers, which reported that BLCs increased with age.[45] Mansouri et al[46] reported that the mean BLC was higher in young smokers than in older people in Birjand, but this difference was insignificant. This study's results are inconsistent with ours, possibly due to differences in population size or diet.

Previous studies have shown frequent and proper use of appropriate PPE results in lower BLCs among workers exposed to lead.[47] In the present study, BLCs were higher among welders who did not use appropriate PPE. Appropriate PPE could effectively reduce lead exposure. Additionally, previous studies have demonstrated that the EPA risk assessment method reduces the amount of pollutants to the lowest possible level to protect the environment and human health. This method is also approved by the WHO.[48] Rahimnejad et al found that the EPA method is more sensitive than the Human Resources of Malaysian method for assessing chemical exposure.[48] Shojaee Barjoee et al used the EPA method to determine the health risk of exposure to inhalable dust and crystalline silica. The results of their study showed that the risk of cancer was about 10^{-6} in all occupational groups, which is consistent with our study.[49]

Our study is one of the few studies carried out in Eastern Iran to determine lead levels among workers. The results revealed that the ALC could be a determining predictor of workers' exposure to lead. To identify other sources of lead exposure among workers, further studies are suggested. Therefore, conducting future studies on long-term exposure to high lead levels with larger population sizes is recommended.

Conclusion

The results of the present study showed that the mean BLC of automobile welders in Birjand and the mean ALC corresponded to the ACGIH standard. In addition, the mean BLC of those who did not use PPE was higher than the mean BLC of other welders. It was also higher in individuals over 30 compared to those under 30. Therefore, the results can provide the information necessary for occupational health measures to reduce lead exposure. Furthermore, the carcinogenic risk of exposure to lead fumes in car welders is within the possible risk range according to CDI and LCR values.

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Authors' Contribution

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Competing Interests

The authors have no conflict of interests to declare.

Ethical Approval

The study protocol was approved by the Committee on Research Ethics at Birjand University of Medical Sciences with approval No. 4794 (ethics code IR.Bums.REC.1396.360). Before participating, welders completed an informed consent form and were assured that all their information would be kept confidential by the research team.

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