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Biomonitoring of Occupational Lead Exposure in a Lead-Acid Batteries Factory

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Abstract

This study assesses lead concentration in blood samples of the LAB workers and the control group and relates their lead exposure to socio-demographic, occupational characteristics, and air lead level. A total of 140 blood samples were analyzed for lead levels. The mean blood lead level (BLL) of workers (55.95 µg/dL) was much higher than that of the control group (8.54 µg/dL). the mean concentration of air lead level(ALL) in most stations (0.30±0.021) was higher than the recommended threshold (0.05 mg/m^3). Analysis of all control samples showed concentrations lower than 0.05 mg/m^3. There was no significant relationship between ALL and BLL (r= 0.423, *P* =0.078). The mean BLLs from the twelve occupational categories were the following, in descending order: alloying (68.11µg/dL), cos/casting (62.17µg/dL), assembly/elbak (58.43µg/dL), ball mill/oxidation (55.78µg/dL), the dough at the beginning of the line (43.56 µg/dL), plastic injection salon (38.35µg/dL), packing (38.11µg/dL), mixing (37.48µg/dL), networking (35.95µg/dL), filling acid (29.33µg/dL), plate cutting (24.3µg/dL) and dough the end of the line(23.43µg/dL). In this study, there was a significant relationship between the related factors including personal protective equipment and work experience with the blood lead levels. We believe that the exposure to lead measured in this study represents the exposure to lead in similar and related institutions in Iran. Specific recommendations for dealing with lead exposure were provided through the use of appropriate engineering controls, personal protective equipment, and personal hygiene. With full implementation of the recommendations, a follow-up study is expected to be conducted to assess lead levels in these facilities.

Keywords: *Lead, Blood lead level, Air lead level, Occupational exposure, Battery Factory*

Introduction

Lead is known as an environmental and occupational pollutant. Lead poisoning is one of the most common occupational and environmental health problems worldwide [1,2]. This toxic substance enters the body through the gastrointestinal tract (eating water and food contaminated with lead), the skin (poor personal hygiene), respiratory tract, and inhalation [3,4]. Due to its bio-accumulation, it can increase toxic concentrations in the human body [4]. The half-life of lead in blood, soft tissues, kidneys, and bones is estimated to be 35 days, 40 days, 7 years, and 25 to 30 years, respectively [5]. Preliminary symptoms and symptoms of exposure to lead include muscle weakness, arthralgia, abdominal pain, general fatigue, weight loss, nausea, vomiting, diarrhea, constipation, dizziness, impaired consciousness, insomnia, optic nerve inflammation, irritability, and headache are symptoms of neurotoxicity [6-9].

Anemia is the classic manifestation of lead poisoning [10, 11]. Exposure to lead can also shorten the life span of Red Blood Cells (RBCs) and inhibition of heme biosynthesis[12, 13]. Chronic lead nephropathy may lead to kidney failure when blood lead levels in workers rise to 60 µg/dL [14-16]. Chronic lead exposure has been associated with increased blood pressure [17]. In the 1960s, BLL (Blood Lead Level) of 60 µg/dL was considered "safe" or "acceptable". According to subsequent research on its harmful effects, the geometric mean blood lead concentration in 1991 to 10 µg/dL gradually lowered [18]. The permissible limit of blood lead by the ACGIH and the Iran Occupational Health Technical Committee is 30 µg/dL [19]. The US Occupational Safety and Health Administration (OSHA) is reported, that when workers' BLLs are equal to or greater than 50 µg/dL (construction industry), employers are required to keep workers away from working in lead-contaminated environments until workers' BLLs fall below 40 µg/dL and then allow them to return to work. Determination of the human risk from exposure to heavy metals is usually done through the determination of metals in biological samples such as blood, blood plasma, urine, hair, nails, and saliva [20, 21]. However, the total amount of blood lead is used as the indicator of lead exposure in the present. BLL is a currently used biomarker of human lead exposure [22]. According to the results of the study done by occupational health experts at Cairo University on the concentration of lead in workers' respiratory air. The average concentration of lead particles (32 mg/m^3) was much higher than the occupational limit and largely led to the occurrence and prevalence of lead-related diseases among workers in this industry [23]. Keramati et al. (2008) tested blood samples from 50 male workers in the battery industry and the results found indicated that blood lead level was (97.6 µg/dl) higher than the "permissible limit" [24]. According to the NAAQS (National Ambient Air Quality Standards), the permissible concentration of ALL (Air Lead Level) is 1.5 µg/m^{3}and the permissible industrial concentration for occupational workers is 50 µg/m^3 (8-hours/day, 5working days per week) [19, 25]. Ibiebele et al. (1994) evaluated the study of 80 blood samples obtained from 20 workers and 80 air samples collected in four operational areas. The geometric mean blood lead concentration found in the casting station, assembly line, battery charge, and sales and management was 92.01, 85.73, 36.31, and, 4.2 µg/m^3, respectively. The corresponding BLLs in the above sections were 32.19, 35.42, 17.33, and 7.78 µg/dL, respectively. There was a positive correlation between BLL and ALL for all the stations and also for the dry and wet seasons. The results of this study also showed that the possibility of predicting BLL by monitoring ALL needs to be evaluated [26]. In Iran, because of enhanced demand in the transportation sector, the use of lead-acid batteries has sharply increased [27]. About 97% of lead-acid batteries in Iran are produced from raw materials. According to an initial survey by the Statistics Center of Iran, there are 40,000 jobs in the battery industry that have a high chance of exposure to lead among the workers, as a result, they are at high risk of lead poisoning. The present study has the following objectives: 1) assess lead concentrations in blood samples of LAB workers (lead-acid battery) and the control group, 2) determine lead exposure levels across the various occupational categories, 3) determine occupational exposure to lead fumes and its relation to blood lead levels among workers and the control group, 4) evaluate the influence of job-related factors and socio-demographic characteristics such as age and years of experience on accumulation lead in the blood samples.

2. Material and methods

2.1. Study population

Table 1: Effect of the socio-demographic and occupation characteristics on mean lead (±standard deviation) concentrations in blood samples.

Parameters		LAB workers (n=70) M±SD	Controls (n=50) M±SD	*P*-value
Age (yr)	25≤	37.65 ± 26.67	7.23 ± 5.1	
	31-26	54.32 ± 44.87	8.34 ± 3.7	0.04
	32≥	64.16 ± 37.43	8.87 ± 4.12	
BMI	20<	27.53 ± 11.64	5.56 ± 2.15	
	25.99-20	35.12 ± 17.18	8.23 ± 5.45	0.188
	30.99-26	48.36 ± 21.21	6.69 ± 3.12	
	40.99-31	55.34 ± 27.35	8.32 ± 3.23	
Education	None	68.11 ± 36.57	5.56 ± 4.23	
	Primary	56.13 ± 33.17	6.23 ± 2.45	0.01

	Middle/JSS	37.19 ± 17.43	6.69 ± 3.12	
	Secondary/SSS & Higher	25.65 ± 11.12	8.32 ± 7.23	
Masks	Always	46.12 ± 21.25	8.34 ± 5.98	
	Sometimes	26.15 ± 12.73	7.23 ± 3.18	0.05
	No	47.24 ± 2.16	7.34 ± 4.11	
Gloves	Always	24.54 ± 11.13	5.65 ± 2.12	
	Sometimes	43.15 ± 22.75	7.13 ± 1.52	0.04
	No	54.78±35.12	8.74 ± 2.10	
Face shields	Always	24.12 ± 13.26	5.14 ± 3.12	0.43
	Sometimes	35.25 ± 13.75	7.23 ± 5.87	
	No	57.16 ± 28.56	8.12 ± 5.12	
Lead intoxication	Yes	54.48 ± 26.24	5.65 ± 1.67	0.01
	No	35.23 ± 16.45	7.13 ± 4.32	
Abdominal pain	Yes	34.15 ± 12.75	6.14 ± 3.43	0.01
	No	54.78±22.12	8.54 ± 4.84	
Hand washing	Yes	24.32 ± 13.21	4.47 ± 2.32	0.03
	No	65.48 ± 39.67	7.12 ± 3.12	
Changing clothes	Yes	27.18 ± 18.21	4.98 ± 2.38	0.048
	No	63.23 ± 39.12	8.12 ± 4.19	
Work experience (yr)	1-5	35.63 ± 11.22	4.36 ± 2.25	0.02
	6-10	48.19 ± 21.76	5.13 ± 2.12	
	11-15	55.18 ± 35.34	6.56 ± 4.16	
	15<	68.11 ± 43.26	8.76 ± 5.13	
Overtime work (hr)	Yes	63.23 ± 39.12	7.26 ± 4.54	0.008
	No	48.23 ± 21.23	5.38 ± 3.24	
Smoking habit	Yes	56.27 ± 26.73	6.23 ± 1.23	0.04
	No	35.63 ± 10.12	7.23 ± 3.18	
heartbeat (Bit/min)		75 ± 3	75 ± 3	
Systolic blood pressure (mmHg)		117 ± 1	118 ± 3	
Diastolic blood pressure (mmHg)		72 ± 2	74 ± 2	

Table 2: Blood lead concentrations in the various occupational categories of the LAB factory

Exposed group/number	BLL (µg/dl) M±SD	Kruskal Wallis Test	*p*-value
Plastic injection salon (n=5)	38.35 ± 16.93	4.34	0.11
The Dough at the beginning of the line (n=4)	43.56 ± 27.84	7.11	0.03
COS/ Casting (n=8)	62.17 ± 35.32	10.15	0.01>
Alloying (n=7)	68.11 ± 43.26	17.26	0.01>
Assembly /Elbak (n=8)	58.43 ± 36.35	7.19	0.02
Plate Cutting (n=5)	24.32 ± 13.21	0.36	0.85
Mixing (n=7)	37.48 ± 13.56	5.24	0.07
Packing (n=6)	38.11 ± 15.46	6.85	0.05
Ball mill /Oxidation (n=8)	55.78 ± 26.89	7.15	0.03
Filling acid (n=3)	29.33 ± 11.54	3.79	0.14
Networking (n=6)	35.95 ± 14.13	4.68	0.10
Dough the end of the line (n=3)	23.43 ± 16.337	0.78	0.67

work

A case-control study was performed among the workers of the lead-acid battery industry located in the west of Semnan province in May 2020. The socio-demographic characteristics and occupational positions of these people are mentioned in Tables 1 and 2, respectively. Health information for workers was reviewed by a physician. Inclusion criteria for participating in the study were: 1) male adult workers who were aged 18 years and above, 2) experience activity in battery production for at least 6 months. Then, a random sampling method was used and workers who were available and willing were sampled and interviewed within each cluster. The same method was used to select donors from the control group (no exposure). In total, 70 blood donors were sampled from the 12 clusters of LAB workers: plastic injection salon, the dough at the beginning of the line, cos/casting, alloying, assembly/elbak, plate cutting, mixing, packing, ball mill /oxidation, filling acid, networking, and dough the end of the line. To eliminate the number of errors and possible contamination during sampling or transfer, 70 people who had office jobs and had no direct connection with battery production acted as a control group. After the blood samples collection, a questionnaire about social and demographic backgrounds (gender, BMI, and literacy level), working characteristics (number of working days, working hours, and environment), occupational lifestyles (smoking, wearing masks, wearing gloves and safety glasses) and signs and symptoms associated with lead poisoning (weight loss, constipation, abdominal pain, etc.) was provided to the participants.

2.2. Air and blood sample collection

Approximately 5 mL of blood was collected at the end of the work shift in BD Vacutainers (SST II plus Advance 10/8.5 ml), containing 1-1.5 mg/ml of K_2EDTA to prevent the coagulation of blood, and placed on a blood tube roller (Micro-Teknik) for 5 min. Then was transferred to the laboratory on dry ice (this sample is stable at 4 °C for 30 days). The Anodic Stripping Voltammetry (ASV) method was used to determine BLL. Due to ethical aspects and to reduce the aggressive effect of blood sampling, measures were taken to perform sampling in line with periodic examination tests. To determine ALL, the $NIOSH_{7300}$ standard was used to measure lead metal in the respiratory area of the worker [28]. According to this standard, an individual sampling pump with a flow rate of 2 L/min (a 25-mm diameter holder) and a cellulose ester filter with a diameter of 37 mm and a 0.8-µm pore size, was used (model XR-44-224-SKC, UK). The sampler inlet was installed at the worker's collar, in the breathing zone around, and downwards, during 8 hours of work.

2.3. Metal analysis

After sampling the respiratory air, the filters containing the sampled particles were transferred to the laboratory and digested in a ratio of 3-to-1 of nitric acid (65%) and perchloric acid (70%) made by the German company Merck and then analyzed by Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES, Perkin Elmer Optima 4300 DV) with a wavelength of 220.353 nm was applied for detecting the concentration of lead. In this method, first, the device (ICP-OES) was adjusted according to the manufacturer's instructions and the calibration curve was drawn to determine the lead level in the samples. Then, the solutions of the main sample were injected into the column and according to the intensity of diffusion and its comparison with the standard curve, the concentration of unknown samples was determined. The detection limit of the device for lead metal was 1 ppb. Due to the difference between temperature and pressure conditions of the sampling site with standard conditions (temperature 25 ° C and pressure 760 mm Hg [101 kPa]), temperature and humidity corrections were made on the sampled air volume. Finally, the obtained values were compared with permissible exposure limits provided (0.05 mg/m^3) by ACGIH (ACGIH 2017), and Iran’s Occupational Health Committee (MHME 2017)[19].

The concentration of lead in the air is using the following equation:

$$C(\text{mg/m}^3)= \frac{c_s v_s - c_b v_b}{v} \quad (1)$$

Here, C is the concentration of lead in the air (mg/m^3) (data from laboratory analysis), C_s is the contaminant concentration in the main sample (data from laboratory analysis), and V_s is the volume of the original sample size (mL), C_b is the pollutant concentration in the control sample (μg/mL) (data from laboratory analysis), and V_b is the volume of control solution (mL). To prepare blood samples for analysis, 0.8 ml of ammonium pyrrolidinedithiocarbamate (APDC-TX) solution and 2 ml of aqueous saturated methyl isobutyl ketone (MIBK) solution were added to 2 ml of blood sample put in a centrifuge tube and were then centrifuged for 4 min with a speed of 4500 rounds per minute (rpm). Finally, all samples were analyzed by flame atomic absorption spectrophotometer (FAAS). All tubes and pipette tips were sterilized with acid before testing (soaked in 10% hydrochloric acid for 24 hours and rinsed with deionized water up to3 times) [29]. The limit of quantification (LOQ) and the limit of detection (LOD) of lead were 2.0974 ng/mL and 0.6292 ng/ml, respectively.

2.4. Statistical analysis

Statistical analysis of the data was performed with software SPSS version 19.0. Findings were analyzed using analysis of variance, correlation test, independent t-test, and Kruskal-Wallis test to determine the significance level of the data. A comparison of mean BLLs of the control and exposed groups was done using a t-test. One-way ANOVA was used to investigate the variation in BLL with the specific job types of the battery industry workers. The Kruskal-Wallis test was used to assess the dependence of BLL on smoking in both the control and exposed groups. In this study, Spearman's correlation test was used to discover the correlation between blood lead and air lead. Among workers exposed to lead, a linear regression model was used to determine the relationship between work and demographic characteristics and blood lead levels. Data with a difference of more than two standard deviations from the mean value are considered outliers and excluded from the analysis. All values are reported as a mean (standard deviation) or a median (interquartile range). A p-value of 0.05 or less is considered significant. All data were expressed as mean ± SD and the level of significance was determined at $p < 0.05$.

3. Results

3.1. Lead concentrations in respiratory air samples

Table 3: The descriptive and analytical statistics and concentrations of lead in the air and blood of workers in the lead-acid battery factory

Sample	Group	No.	Mean±SD	Min	Max	*P*-value
ALL(μg/m³)	LAB workers	70	0.30 ± 0.021	0.004	1.14	0.13
	Control	70	0.04 ± 0.03	0.001	0.004	
BLL (μg/dl)	LAB workers	70	55.95 ± 8.24	24.32 ± 13.21	68.11 ± 43.26	0.16
	Control	70	8.54 ± 5.23	4.36 ± 2.25	8.87±4.12	
BLL (μg/dl)*						
r				*P*		
ALL(μg/m)						
	0.423			0. 078		

*Pearson correlation test

In
table 3, the mean and standard deviation (±) concentration of lead in the respiratory air is shown. We found the concentration of air lead in 9 workstations was higher than the permissible limit and only in 3 workstations was lower than the permissible limit (30µg/dL- ACGIH). Therefore, approximately 90% of the stations surveyed in this industry had polluted air and were above the permissible limit. Among the monitored stations, the highest lead concentration and highest exposure levels were related to the alloy-assembly hall station (1.5 ± 1.07) and elbak operator (1.8 ± 0.61), and the lowest exposure level was related to the packing station (0.003 ± 0.04). In general, the mean concentration of air lead in most stations (0.30 ± 0.021) was higher than the recommended threshold (0.05 mg/m^3). Analysis of all control samples showed concentrations lower than 0.05 mg/m^3.

3.2. BLLs among LAB workers and control group

This finding shows that the mean BLL of the control group was much lower (8.54 µg/dL) than the LAB workers (55.95 µg/dL). Table 1 shows the average BLL of workers (participants) based on work experience, working hours, use of personal protective equipment, and personal habits. The mean BLL of the workers varied with the working hours of the workers. For example, the mean BLL was higher in workers who worked more than 8 hours per day compared to workers who worked up to 8 hours per day in both groups (P = 0.008). The mean BLL of smokers was higher than non-smokers. So there was a significant difference between smokers and non-smokers (P=0.04). Workers who used the regular mask had significantly lower BLL compared with those who did not (P = 0.53). A t-test analysis shows that there is a statistically significant difference between the BLLs of LAB workers and the control group.

3.3. BLLs and LAB occupational positions

We examined the distribution of lead levels among different occupational categories and found higher BLLs among LAB workers compared to the US ACGIH reference level. Table 2 compares the BLLs of LAB work categories based on the ACGIH standard. The results of this study show the exposure rate of workers to lead contamination caused by LAB production processes at each stage of the production chain. The average BLL of twelve job categories in descending order was as follows: alloying (68.11µg/dL), cos/casting (62.17µg/dL), assembly/elbak (58.43µg/dL), ball mill/oxidation (55.78µg/dL), the dough at the beginning of the line (43.56 µg/dL), plastic injection salon (38.35µg/dL), packing (38.11µg/dL), mixing(37.48µg/dL), networking (35.95µg/dL), filling acid (29.33 µg/dL), plate cutting (24.32 µg/dL) and dough the end of the line(23.43µg/dL). Workers working in the alloying station showed higher BLLs than other stations in the production chain. A significant concentration of lead (37.65 µg/dL) was found in the blood of a 23-year-old worker who had been working at a cos/casting station for 4 years with a working time of 48 hours per week. This finding is similar to the study of Ibiebele et al. (1994). They showed that workers working in the casting station and assembly line had the highest levels of elemental biomarkers compared to other LAB production chains [26]. In our study, the majority of workers at alloying and casting/casting stations had much longer working years and spent more time in the plant. This long-term exposure to lead can occur through direct skin contact, ingestion, and inhalation of lead, which usually results in elevated BLL.

3.4. Relationships between job-related factors and BLLs

The study also explored the relationship between socio-demographic characteristics, working characteristics, occupational lifestyles, and the impact of chronic symptoms on participants' BLLs. Table 1 presents participants' sociodemographic and occupational characteristics. The results show that BLLs in LAB workers increased with age. This means that older workers have more BLL than younger ones. For example, workers under 25 years of age had the lowest mean BLL (37.65 µg/dL), while those between the ages of 26–30 years and <31 years had mean BLLs of 54.32 µg/dL and 64.16 µg/dL, respectively. This finding is consistent with Dehghan Nasiri et al. (2012). In this study, a significant relationship was found between the age of LAB factory workers and blood lead [30]. Also, this study is consistent with the study of Fang et al. (2021) in Taiwan. They showed that older men had higher BLL than their younger peers. According to these researchers, the observed trend may be due to the increased exposure of older workers over time, along with their lower disposal rates [31]. Body mass index (BMI) was unrelated to lead level measured in LAB workers ($p > 0.05$). Mohammadyan et al. (2019) study in Iran showed that there not was a positive and significant correlation between BMI and lead in blood [6]. Our study also investigated whether working years and hours of factory workers predisposed them to higher BLL. In terms of years of work, the findings show that the number of years the workers have spent in the LAB factory ranged from 1 to 20 years, with the majority working less than 10 years while the rest worked 10 years or more. Regarding overtime hours, the results show that the majority of workers worked between 60 and 75 hours per week (12 to 15 hours per day), while a smaller number of workers worked between 45 and 55 hours per week (9 to 11 hours per day). The results show a direct relationship between the BLLs of the participants' and the overtime working hours spent in the LAB factory. For instance, workers who recorded the highest mean overtime working hours of 15 had the highest BLL (63.23µg/dL), while the workers who did not have the overtime working hours, had the lowest mean BLL (38.23 µg/dL). The t-test analysis showed a significant level of 0.008 between overtime hours and BLL. This analysis showed that the working hours spent in the LAB plant affect the changes in BLL. Therefore, this finding reiterates our previous claim that longer stay in the factory increases BLL in LAB factory workers. This finding is consistent with Ahmed et al.'s (2018) study, who showed that lead concentrations in blood samples of older automobile technicians (over 45 years) are higher, which in turn leads to unequal degrees of occupational risk [22]. Our study goes further by examining social habit/lifestyle variables such as smoking, hand washing, frequently changing work clothes, wearing gloves, wearing safety shields, and wearing masks. The results show that only two variables have no significant relationship with blood lead level of LAB factory workers and control group. These included BMI and helmet wearing. The frequency of changing work clothes was also measured as a dummy variable, where people who changed their clothes every day had lower blood lead levels compared to workers who rarely changed their clothes. Our findings show that not changing clothes can increase the blood lead level of workers to a concentration of 63.23 µg/dL compared to their counterparts who changed their clothes daily ($p<0.05$). Among these factors, cigarette smoking ($p < 0.01$) and education ($p < 0.05$) were significantly associated with increases in blood lead levels. Jung et al. (2015) have indicated that there is a significant association between smoking and blood lead levels [32]. There is a significant relationship between blurred vision related to jobs and blood lead levels ($P<0.05$). Our finding implies that lead intoxication and abdominal pain were significantly associated with increases in blood lead levels($p<0.05$). The results of Alinejad et al. (2017) showed that there is a significant relationship between blood lead concentration with depersonalization and low performance of staff ($P< 0.05$) [33]. In another study in a Car Battery Plant (Iran), all workers had lead intoxication with a mean BLC of 32.2± 13.7 µg/ dL [24].

3.5. Relationship between Air Lead Level (ALL) and Blood Lead Level (BLL)

As shown in Table 3, the average blood lead concentration of the workers was (55.95 µg/dL), with a range of 24 to 68 µg/dL, which was higher than the standard of biological exposure indicators in Iran (Occupational Health Technical Committee, 2004(30 µg/dL)). In some similar studies, Keramati et al. (2009) [24] found the blood lead level of workers in a Car Battery Plant (Iran) was 34µg/dL while Ahmad et al. (2018) [22] found the blood lead level in Pakistani workers was 65 µg/dL (Above the recommended limit of ACGIH). The mean BLL of the exposed groups was significantly higher than the control groups. Figure 1 shows the comparison of mean blood lead levels (µg/ dL) between exposed and control groups with air lead levels in 2020. This Figure has demonstrated a clear increase in the mean BLLs of the exposure group. The distribution of values in each group is relatively comparable. However, regarding the spearman test, no significant correlation between BLL and ALL was not found ($r = 0.423$, $p = 0.078$) (Figure 1). Airborne lead pollution could not be a key exposure pathway for elevated blood lead levels among LAB plant workers. Therefore, there are other routes such as digestion and skin contact for exposure to lead, but there are several studies that show inhalation of air as the main route of exposure to lead in workers [19].

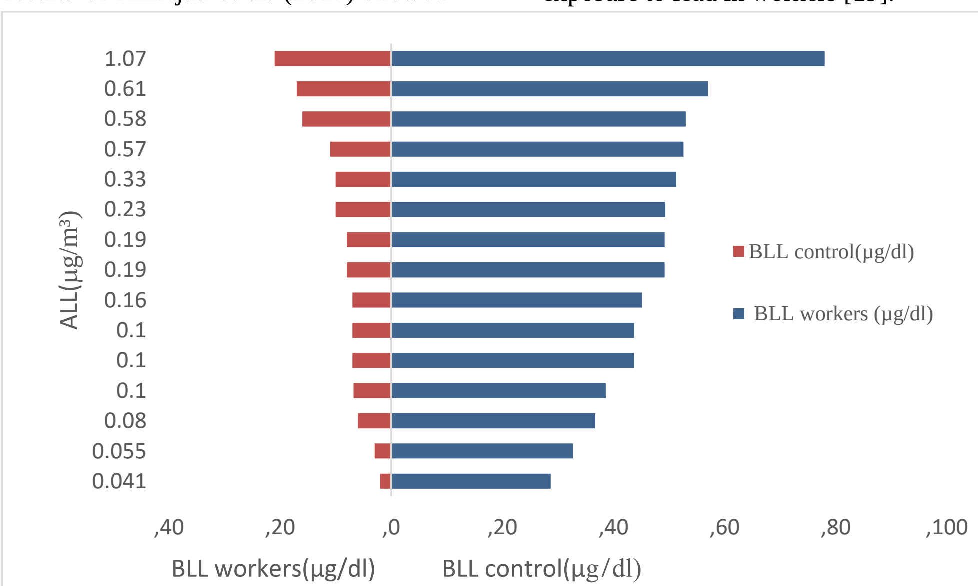

Figure 1: Comparison of mean blood lead levels (µg/dl) between workers and Control group with air lead levels

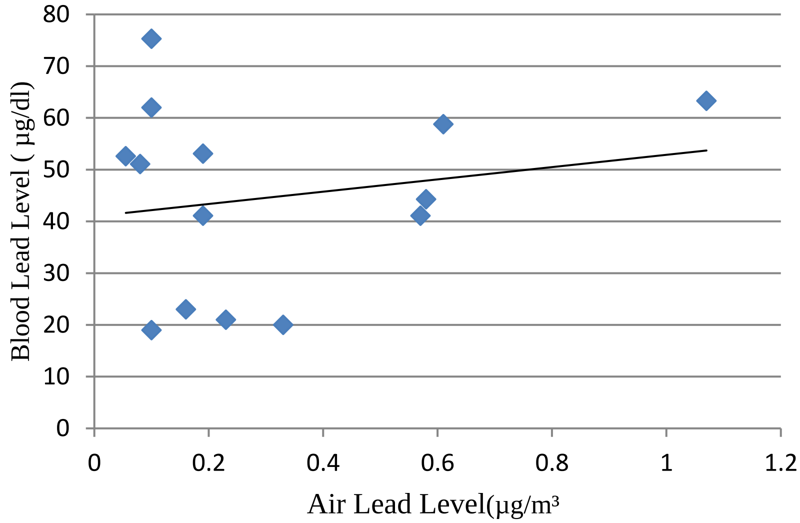

Figure 2. Correlation between the blood lead level (personal sampling) and the air lead level of the workers by linear regression line (r= 0.423, p= 0.078)

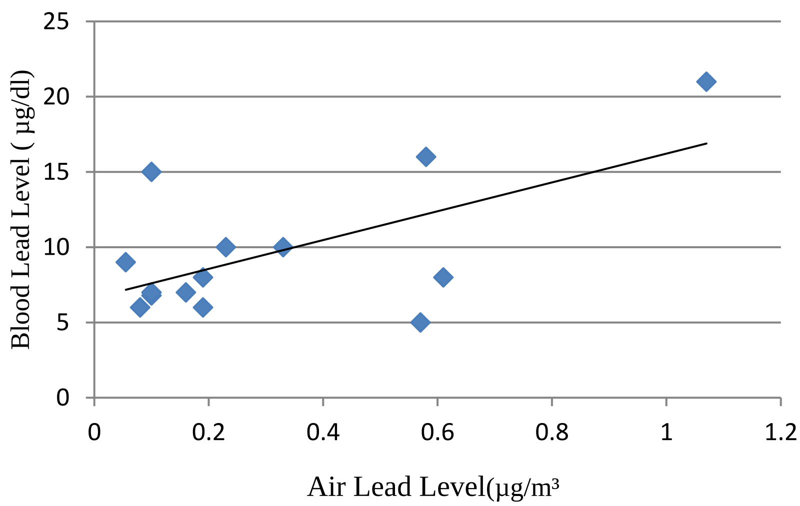

Figure 2. Correlation between the blood lead level (personal sampling) and the air lead level of the control group by linear regression line (r= 0.423, p= 0.078).

4. Discussion and Conclusion

4.1. Discussion

In this study, we investigated production processes in 12 workstations including; alloying, cos/casting, assembly/elbak, ball mill/oxidation, the dough at the beginning of the line, plastic injection salon, packing, mixing, networking, filling acid, plate cutting, and dough the end of the line (23.43µg/dL), where workers were directly exposed to lead. In these sections, the mean BLL of workers was more than the permissible limit. The mean BLL of the exposed and control groups was 55.95 and 8.94 µg/ dL, respectively, which is more than the permissible limit set in the country, i.e. 30 µg/ dL. According to the guidelines, if the workers' BLL exceeds 60 µg/ dL once or if the BLL exceeds 50 µg/ dL in the last 6 months, the worker must be fired. If the BLL is less than 40 µg/ dL in a random sequence, the workers can return to their work environment [28, 34]. Another study reported, that 28% of LAB workers in Jamaica had BLL less than 60 µg/ dL. ALL reported in the same study was 0.03-5.3 µg/dL [35]. A study was performed in a car battery factory on workers who were exposed to lead, results showed that the mean BLL (32.2±13.7 µg/ dL) of the workers was higher than the findings of the present study [24]. This difference may be due to the type of production process, the type of equipment used, the amount of moisture, the natural ventilation, and the absorbent used in the factory. Due to the higher amount of lead in workplace air, it was expected that there was a significant correlation between BLL and ALL, but there was no connection. A correlation coefficient of positive indicates that the relationship is consistent, but due to the low value of the correlation coefficient, it can be said that there is no significant relationship between workers' BLL and ALL of them. These results may be due to the small sample of the population, exposure to other means except inhalation, such as lead-contaminated hands and clothing, and the use of inappropriate personal protective equipment. The study conducted by Woo et al. (2018) in the Munshiganj District of Bangladesh to determine the association of children's BLL with elevated lead concentrations in the air showed that residential and industrial air samples had high lead concentrations (mean 1.22μg/m^3) but was not found to be related to blood lead levels [36]. Medinilla and Espigares (1991) found a significant correlation between blood lead and air lead [37]. However, in most similar studies, there was no significant correlation between the contents of heavy metals in blood and air [38]. In Adela's study and other similar studies, it was shown that the blood lead of the exposed groups had a significant difference from the control groups, this is due to the high exposure of workers in the soldering section to increased lead in the respiratory air and as a result, lead to increased lead in their blood lead [39]. The significantly positive correlation between $PM_{2.5}$ and topsoil lead and BLLs in Chinese adults showed that air and soil pollution affects adult BLLs [40]. A comparison of BLL in smokers and non-smokers in this factory showed the mean BLL of smokers in exposed groups (56.27±26.73 μg/dL) was significantly higher than that of non-smokers (35.63±10.12 μg/dL). The workers in the present study were mostly young (25≥ years old). Due to the current age of the workers and their work experience, most of the workers were exposed to lead from a young age and continued for a long time. In the case of the work experience and overtime work, the results of the present study are also consistent with the results of the study of Nasiri et al. (2012) [30]. The results of the study by Adela et al. (2018) showed that the BLL of men (68.45 μg/ dL) was higher than women (56.51 μg/dL), smokers (80.96 μg/ dL) higher than non-smokers (58.95 μg/ dL) and population over 40 years (40.43 μg/ dL) is higher than young population (40.37 μg/ dL). In this study, there was a significant relationship between the related factors including wearing masks, wearing gloves, hand washing, and changing clothes with the blood lead levels. Relatively high levels of blood lead in workers in the lead industry are attributed to absorption through the skin and inhalation, especially in cases where the use of personal protective equipment such as masks is irregular [41,42]. Lead can be absorbed by body fluids (blood) and quickly excreted through sweat and urine. Studies conducted in tropical regions have observed a significant relationship between blood lead level and sweat lead level [43]. Liang et al. showed that the highest amount of lead from lead-exposed workers was detected in the workers of the lead-acid battery industry in Guangzhouin, China: 2006–2019 [44]. Battery manufacturing workers in Mexico have the highest average BLL worldwide [45]. The results of the comparison between the control group and workers exposed to Pb showed that DNA damage caused by Pb was closely related to the methylation of genes in cell cycle regulation, and the methylation levels of RRAGC were involved in genotoxicity caused by its [46]. The data obtained from the studies can be used to support adaptive community health and risk assessments, economic analyzes, and risk management decision-making to evaluate site cleanup and risk mitigation options as the most cost-effective and efficient method [47]. In an occupational lead exposure study conducted with 102 male patients, it was found that there is a positive and significant relationship between blood lead level and anxiety, depression, trait anger, suppression and anger release, and a negative relationship with the ability to control anger [48]**.** In a cross-sectional study with 85 potters of Maragogipinho Village, Brazil, aged 16–72 years and 50 Non-exposed workers of the same age range, the mean PbB for the exposed group was 7.9 (0.9-49.8) μg/dL and for the control group was 1.5 (0.1-19.8) μg/dL [49]. The results of the study by Kargar et al. (2022) showed that most blood parameters, including red blood cells, hemoglobin, mean cell volume, mean cellular hemoglobin, and mean corpuscular hemoglobin concentration, were significantly reduced in battery industry workers. Therefore, occupational exposure to lead above the threshold is associated with hematological symptoms and liver and kidney dysfunction [50]. Hanser et al. (2022) found that administrative and sorting workers were exposed to lower levels of metals (Cd, Co, Cr, Li, Mn, Ni, and Pb) than battery maintenance, treatment, and dismantling workers [51]**.** AdolfoChavez-Garcia (2022) found that battery workers have the highest mean difference in blood lead levels in the world. But the relationship between exposure to lead sources and blood lead levels in exposed people is not clear [52]. The strong correlation between BPb and smoking was also reported by Anouar Nouiou et al. (2018) for battery workers (0.047=P) [53]. Our study showed, that the production line workers ate their meals while wearing their work clothes, very often did not wash their hands before smoking, there was little evidence of showering and dirty clothes with clean clothing were stored. So, health education includes cleaning the workplace after daily work, taking a shower daily after work, use of personal protective equipment such as special masks, protective clothing, and gloves, and prohibiting drinking, eating, and smoking in the different work areas as a basic tool in the prevention of occupational diseases should be repeated at least yearly for each worker.

4.2. Conclusion

This study provides a baseline of the lead exposure levels in the battery factory in Iran. We believe that the exposure to lead measured in this study represents the exposure to lead in similar and related institutions in Iran. The results of this study were shared with relevant authorities to serve as a basis for formulating lead exposure policies for affected workers. Specific recommendations for dealing with lead exposure are provided through the use of appropriate engineering controls and local ventilation systems, personal protective equipment, and personal hygiene. With full implementation of the recommendations, a follow-up study is expected to be conducted to assess lead levels in these facilities.

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Conflicts of interest

There are no conflicts of interest

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