



Original Article

Assessment of Exposure to Toxic Occupational Elements Among Electronic Repair Workers in Quchan City, Iran

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Abstract

Nowadays, the adverse effects of toxic metals on humans are well-known. Large-scale production and the demand for new electronic devices have made electronic components a significant source of toxic elements. This work focused on examining the exposure to residential toxic metals and metalloids in electronic components repairers by analyzing their scalp hair and nail samples. In this study, 19 electronic component repairers were selected based on the required criteria for the study, including different ages and employment durations. Hair and nail samples as biological tissues were collected from them and analyzed to detect the toxic elements. The results showed that smoking and filled teeth were effective in increasing the value of toxic elements in these people. High levels of Zn and Sn were obtained in the nails compared to hair samples, including 310.5 and 204.7 $\mu\text{g/g}$ for nails and 254 and 77.1 $\mu\text{g/g}$ for hair, respectively, and the concentration levels of the studied elements were found in the rank order of $\text{Zn} > \text{Sn} > \text{Pb} > \text{Ni} > \text{As} > \text{Se} > \text{Cr} > \text{Cd}$. Our study confirmed that there was a strong correlation between nail selenium content and nail As burden ($r=0.907$, $p=0.028$). We realized that Sn and Pb had a strong correlation together due to the use of solder joints in the repairing process by the repairers. This study shows that human scalp hair and nails could be useful biomarkers to assess the extent of toxic metal exposure in the repairer of electronic components.

Keywords: Toxic metal bio-accumulation; Electronic repairers; Solder joints; Lead and tin

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1. Introduction

The growing demand and manufacturing of electronic devices in recent decades have led to challenges for both people and the environment (Fu et al. 2008). Recycling electronic waste (E-waste) in developing nations contributes to the influx of toxic metals that can contaminate local ecosystems. Regrettably, many individuals opt for used electrical and electronic devices in these regions

due to their lower costs. Currently, we are aware that common e-waste items, such as cathode ray tubes (CRTs) and circuit boards, contain arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn). Toxic metals fall under the category of non-biodegradable pollutants in the environment, which can enter the human body through various pathways and subsequently accumulate within it (Fujimori et al. 2012). Numerous

metals, along with metalloids like arsenic (As), are crucial micronutrients (such as iron (Fe), copper (Cu), zinc (Zn), chromium (Cr), and arsenic (As)), but they can be harmful when present in higher concentrations than those typically needed. In contrast, some metals, including cadmium (Cd), mercury (Hg), and lead (Pb), are not biologically necessary and can be toxic to living organisms, even at minimal levels, ultimately posing significant health threats to both humans and ecosystems (Ekine et al. 2023; Liang et al. 2017).

Among dangerous toxic metals, Cd is a basic concern because of its adverse effects (Garcia-Esquinas and Perez-Gomez 2013). Even the low concentrations of Cd can cause low birth weight (H. Li et al. 2019), premature delivery, and changes in thyroid hormone levels in newborns (Garcia-Esquinas and Perez-Gomez 2013). It is important to highlight that cadmium is significantly absorbed into the human body through smoking (Thompson and Bannigan 2008). For individuals who do not smoke, the primary sources of cadmium exposure are polluted water and workplace exposure (Nishijo et al. 2004; Oskarsson et al. 2004). Conversely, prolonged exposure to lead can result in miscarriage (Borja-Aburto et al. 1999), congenital malformations (Needleman et al. 1984), spontaneous abortion, low birth length (Hernandez-Avila et al. 2002), high blood pressure in pregnancy (Kennedy et al. 2012), and impaired neurodevelopment. Furthermore, it has been documented that exposure to mercury in the workplace can lead to hypertension during pregnancy (Pan et al. 2007), decreased birth weight (Ramon et al. 2009), birth malformations (Jin et al. 2013), developmental delays, and memory loss (Surkan et al. 2010). High levels of mercury in the body can result from dental amalgam, as well as from bleaching creams and cosmetics (Al-Saleh et al. 2011, 2014; Wells et al. 2010).

Studies on e-waste recycling sites in Asia have revealed hazardous metal pollution in various environmental media, including the air, soil, and water (Fujimori et al. 2012b), sediments (A. Leung et al. 2006), and dust (A. O. W. Leung 2008). High blood Pb levels in children, Pb concentrations in the placenta, and urinary toxic metal levels (Fujimori et al. 2012), Cu and Pb in human scalp hair (Wang et al. 2009), and elevated levels of lead in umbilical cord blood and in the meconium of newborns have been found in proximity to e-waste recycling facilities, as documented by Chen et al. (Fujimori et al. 2012). Of the different environmental media analyzed, dust exhibited the highest concentration of metals in studies conducted in e-waste villages located in southeastern China (Fujimori et al. 2012).

Given the varying effects, it's crucial to track the levels of toxic metals, as they play a significant role in evaluating the potential health threats posed by these metals to individuals. Nevertheless, research has indicated that evaluating air, water, and soil samples produces data that can be unreliable for determining the health risks associated with environmental pollution, since the actual extent of toxic metal contamination can differ greatly within a specific region (Liang et al. 2017). Recently, human nails have gained recognition as a crucial tissue for assessing environmental exposure in humans, as they accurately reflect exposure to various toxic and essential trace metals over time (Samanta et al. 2004). Studies have indicated that the levels of toxic metals found in nail tissue are often greater than those present in body fluids and other easily accessible tissues (Sukumar and Subramanian 2007).

For several years, the significance of hair analysis in tracking toxic metal levels has been recognized (Liang et al. 2017). Human hair can accumulate toxic metals (Censi et al. 2012), and as it grows, it can integrate these metals into its structure as a metabolic byproduct. Consequently, the levels of toxic metals found in hair can indicate the average concentration in the human body, reflecting the exposure of the population to toxins over time (Liang et al. 2017).

Additionally, blood and other bodily fluids are not appropriate for analyzing Cd levels, as the metal has a brief presence in these media. Moreover, human hair and nails possess several advantages, including greater stability, ease of collection and transport, convenient storage, and the ability to indicate long-term exposure to toxic metals and elevated metal concentrations compared to other biological indicators (Surkan et al. 2010). Thus, human hair and nails are deemed effective screening methods for a comprehensive evaluation of toxic metal levels (Al-Saleh et al. 2011, 2014; Wells et al. 2010). Several recent studies have reported using hair or nail analysis to gather data on toxic metal concentrations (Liang et al. 2017; Samanta et al. 2004; Solgi et al. 2018; Wang et al. 2009).

To our knowledge, there has been limited exploration of toxic metals in hair as a means to evaluate exposure to e-waste activities, making our study one of the few to examine human exposures to toxic metals among electronic component repair workers. The findings from this research can support other scholars and address gaps in global research databases that may arise due to a lack of data from Iranian society. Since electronic components contain significant levels of specific toxic metals, such as As, Cd, Ni, and Pb, this study concentrated on

investigating the exposure to these harmful metals and metalloids among electronic component repairers by analyzing samples of scalp hair and nails.

2. Methodology and Data

2.1. Setting and sampling

In this research, all 19 electronic component repair technicians from Quchan City, situated in Khorasan Razavi province in the northeast region of Iran (as illustrated in Fig. 1), were chosen according to the necessary criteria for the study, from a population of 174,500 in 2022. Hair samples (ranging from 100 to 500 mg and measuring 3–5 cm in length) were obtained using pre-cleaned stainless-steel scissors to minimize the risk of external contamination. This method provided hair samples that represented exposure over the previous 3–4 months.

For the collection of nail samples, participants were instructed to thoroughly wash their hands and toes with medicated soap and rinse them with double-deionized water to prevent metal contamination, followed by drying with a clean towel or tissue to eliminate any external contaminants. Fingernail and toenail samples were cut using sterilized stainless-steel scissors. All nail samples were subsequently sealed in plastic bags before analysis. The sampling process was conducted with ethical approval from the Ethics Committee of Sabzevar University of Medical Sciences, with code IR.MED-SAB.REC.1395.67, and informed consent was obtained from all individuals. Furthermore, all methods were carried out in accordance with relevant guidelines and regulations.

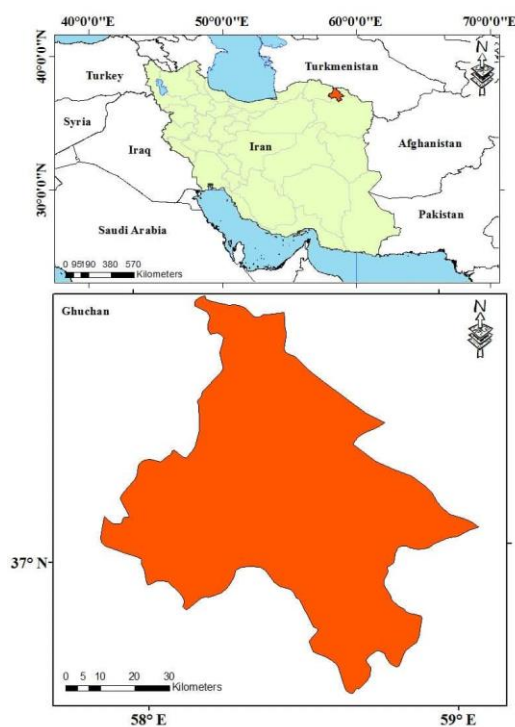


Fig.1. The geographical location of Quchan city in Iran.

2.2. Sample preparation

The hair and nail samples were chopped into small pieces to facilitate efficient and rapid acidic digestion of the materials. Initially, hair and nail samples were washed with a nonionic detergent and immersed in deionized water for a duration of ten minutes. This was succeeded by a soak in acetone to eliminate surface contamination, after which the samples were rinsed with deionized water. The samples were then dried in an oven (ATRA, Iran) at a temperature of 70 °C for one hour and subsequently stored in a sealed polyethylene container until analysis. For each hair and nail sample, approximately 0.5 grams of the ground material was carefully measured and placed into a clean Teflon container. The samples underwent digestion with 8 ml of concentrated nitric acid and were left at room temperature for 12 hours. Following this, 2 ml of concentrated perchloric acid was introduced to the solution, and the resultant mixture was subjected to a stepwise heating process in a microwave digester (ETHOS UP, Italy) for one hour at 80 °C, followed by three hours at 150 °C. After allowing it to cool to room temperature, the clear supernatant was separated and diluted to 25 ml with deionized water, followed by analysis using inductively coupled plasma mass spectrometry (ICP-MSHP-4500, USA). In this study, the levels of Zn, Sn, Pb, Ni, As, Se, Cr, and Cd in the hair and nails of electronics repairmen were analyzed.

Standard reference material (SRM) was utilized to assess the accuracy of the analysis for toxic metals. Every control and sample was analyzed in triplicate. Whenever the performance metrics of the method indicated inadequacy, the method was modified and subsequently verified. In this procedure, a control sample was included for at least 10% of each series of samples. The average recovery of the standard reference material was approximately 95% (ranging from 85% to 110%). Furthermore, to evaluate the precision of the analytical method, the relative standard deviation (RSD) was calculated as well.

2.3. Statistical Analyses

To evaluate the data's normality, the Shapiro–Wilk test was utilized. Continuous variables were reported as either mean (\pm standard deviation) or median (IQR), based on their distribution. Categorical variables were displayed as frequencies (%). The Spearman and Pearson tests were used to analyze correlations among the variables, and the T-test and ANOVA tests were used for the assessment of the association between heavy metals and related factors. Data analysis was conducted using Stata software (Version 16, Stata Corp, College Station,

Texas, USA). A p-value of less than 0.05 was considered statistically significant.

3. Results and Discussion

3.1. Descriptive statistics

In this study, the levels of Zn, Sn, Pb, Ni, As, Se, Cr, and Cd in the hair and nails of electronics repairmen were investigated. As researchers have shown, hair and nails are considered good bio-indicators for measuring and monitoring toxic metals in the human body. During hair growth, this tissue acts as a repellent to metabolically remove accumulated metals, and nails are thought to act like hair. Therefore, in this study, hair and nails were used as a non-invasive method to investigate the levels of heavy metals in electronics repairmen (Solgi et al. 2018).

In the present work, 19 volunteers were selected as the test sample and 5 individuals as the control sample. The age of electronic components repairers was in the range of 28-74 years with an average of 39.7 ± 9.3 years (Mean \pm SD). On the other hand, the age of 13 persons was above 35 years old. The age range of the control group was between 26 and 45 years, with an average of 35.2 ± 6.3 years (Mean \pm SD). The average concentrations of the toxic metals according to relevant standard deviation (SD) values are listed in Table 1.

The total toxic metal concentration values in all samples were observed to be higher in the nails than in the hair samples. Unfortunately, there are not many studies investigating the toxic metals in the hair and nails of electronic component repairers. As shown in Table 1, the average concentration for elements had a rank order as $Zn > Sn > Pb > Ni > As > Se \geq Cr > Cd$. In this regard, some repairers had extremely high levels of 310.5 and 204.7 $\mu\text{g/g}$ in the nails and 254 and 77.1 $\mu\text{g/g}$ in the hair samples for Zn and Sn, respectively. These levels were higher than those obtained for the control group, as 233.7 and 28.6 $\mu\text{g/g}$ for nails and 233.7 and 8.6 $\mu\text{g/g}$ in the hair samples for Zn and Sn, respectively.

3.2. Investigation of Zn and Cd in the samples

Although the high concentration of zinc occurs due to unhealthy nutrition and contaminated drinking water, environmental conditions also play an important role in intake.

The lowest concentration level was related to Cd, with an average of 0.2 ± 0.5 $\mu\text{g/g}$ in the hair and nails of the volunteers, while this value was zero for the control group. As other researchers reported, in the hair samples, zinc has had the highest level, while the lowest level has been related to cadmium (Solgi et al. 2018). The same results were also obtained in the study of Samanta et al.

(Samanta et al. 2004), Li et al. (Y. Li et al. 2020), Novak et al. (Nowak and Chmielnicka 2000), and Pereira et al. (Pereira et al. 2004).

The acceptable maximum level for body Zn content has been proposed as 2000 to 3000 $\mu\text{g/g}$ by WHO (Chaudhry 2017). In the present study, the amount of zinc obtained in the nails of the testing samples was less than the acceptable levels of the WHO guidelines.

According to Akan et al. (Akan et al. 2012), zinc content was linked to the highest metal concentrations found in both hair and nails, and the concentrations of hazardous metals in the nail samples were much higher than those in the hair samples. All elements except As were found at lower levels than in an electronic waste recycling area in Taizhou, China, with As showing around 3 and 9 times higher in the hair and nails, respectively.

Examination of lead and zinc levels in 18 to 60-year-old roadside workers showed that lead and zinc concentrations in the nails of people working in busy areas were higher than those working in other areas (Mehra and Juneja 2005). However, in the case of Cd, Se, As, Ni, and Cr, the average amount is higher in people with high work experience. In our study, there was no significant difference in the amount of cadmium in the hair of the individuals between the two study groups, and on the other hand, it was less than the acceptable level reported by the WHO (10 $\mu\text{g/g}$).

3.3. Investigation of Sn and Pb in the samples

The primary source of exposure to Sn and Pb for electronic repair workers is from solder joints, which typically consist of 60 wt.% Sn and 40 wt.% Pb. As indicated in Table 1, the concentrations of Sn are significantly higher than those of any other metals analyzed. In individuals with more than 3 filled teeth, the average levels of Sn detected in hair and nails were found to be 122.2 and 273.3 $\mu\text{g/g}$, respectively. Tin (Sn) does not have any known biochemical role within the human body. According to Tables 1 and 2, the levels of Sn are substantially higher than those of any other metals studied. Tin may be released from solder utilized by electronic repairers. It can also originate from the manufacturing and application of tin and its compounds, as well as from agricultural practices, for instance, the use of certain pesticides. Tin-coated materials are frequently used for packaging food and beverages, potentially contributing to dietary exposure, particularly when cans have plain, uncoated interiors. A high intake of canned foods may lead to digestive issues. Furthermore, tin toxicity can disrupt the functioning of various enzymes, which in turn affects the metabolism of Zn, Cu, Fe, and Ca, and alters the

concentrations of several other elements within organ tissues (Peraza et al. 1998). Cigarette smoking has led to a significant increase in mercury and tin levels in the human body. In contrast, the levels of other elements, such as aluminum, copper, zinc, and lead, tend to be higher in non-smokers. Also, we found that the concentrations of elements Cr, Ni, As, and Se did not show significant differences between smokers and non-smokers.

Table 1. Toxic metal concentrations in hair and nails of the electronic component repairers ($\mu\text{g/g}$).

Independent variable	As		Se		Cd		Sn		Cr		Ni		Pb				
	Hair	Nails	Hair	Nails	Hair	Nails	Hair	Nails	Hair	Nails	Hair	Nails	Hair	Nails			
Number of filled teeth	0	Mean±SD	0.91.1±	5.6±2.8	0.7±0.8	0.8±0.2	0.1±0.2	0.2±0.1	104.8±170.3	361.4±1 13.6	1±0.5	1.3±0.3	2.4±2.7	4.5±1.3	22.6±38.6	25.4±3.5	
		Median	0.4	5.1	0.4	0.8	0	0.2	26.9	388.6	1	1.3	1.8	4.5	3.8	24.2	
	1-3	Mean±SD	0.6±0.6	2.3±2.2	0.7±0.2	1.3±0.6	0.3±0.7	0.1±0.1	34.8±23.6	89.4±52 .5	1.2±2.2	1.1±0.5	1.2±0.6	4.1±2.9	80.9±220.4	139.3±3 48.2	
		Median	0.2	1.7	0.7	1.5	0	0.1	27.7	93.4	0.3	0.9	1.1	3.2	7.5	19	
	3≤	Mean±SD	2.1±4.3	4.7±5.9	1±0.4	1.7±1.2	0.1±0.1	0.3±0.4	122.2±142.2	273.3±3 63.3	0.7±0.6	1.2±0.5	2.4±1.2	4.5±2.5	13.6±11.6	35.5±25. 5	
		Median	0.3	1.7	0.9	1.4	0.1	0.1	36.7	135.7	0.5	1.1	2.7	4.5	9.4	28	
Age, year	<35	Mean±SD	0.9±1.1	3.2±4.3	0.7±0.2	1.3±0.5	0.1±	0.1±0	30.7±14.5	134.2±1 38.8	0.4±0.2	1±0.5	1.4±1.2	4±1.9	8.1±3.9	20.6±7.4	
		Median	0.4	1.6	0.6	1.5	0	0	32.3	89	0.4	1	1	4.5	7.5	19.4	
	35≤	Mean±SD	1.2±2.7	3.9±3.9	0.8±0.5	1.3±0.9	0.2±	0.2±0.2	89.5±123.2	223.6±2 51.3	1.1±1.7	1.3±0.5	1.9±1.6	4.4±2.5	57.8±170.1	99±268. 4	
		Median	0.3	2.8	0.7	1.1	0	0.2	36.3	129.8	0.6	1.2	1.5	3.5	6.3	25.1	
	Employment time, year	<10	Mean±SD	0.6±0.2	3.1±3.2	0.6±0.2	0.9±0.5		0.1±0.1	24.7±14.7	116.2±1 18.5	0.5±0.3	1±0.4	1.1±1		100.1±250.7	168.3±3 96.5
			Median	0.6	2.8	0.6	0.8		0.1	20.1	93.4	0.3	0.9	0.8		4.8	19
10≤		Mean±SD	1.5±3.2	3.3±3.3	0.9±0.5	1.6±0.9			87.3±117.1	267.9±2 79	1.3±1.9	1.4±0.5	2.1±1.6	5.3±2.5	15.2±22.4	32.7±19. 1	
		Median	0.6	2.7	0.9	1.6			37	141.7	0.6	1.3	1.8	4.8	6.3	24.6	

Independent variable	As		Se		Cd		Sn		Cr		Ni		Pb		
	Hair	Nails	Hair	Nails	Hair	Nails	Hair	Nails	Hair	Nails	Hair	Nails	Hair	Nails	
Smoking	Mean±SD	0.3±0.4	3.4±2.6	0.7±0.3	1.4±0.5	0.4±0.9	0.1±0.1	25.5±14.8	24.8±13.5	1.6±2.6	1.2±0.6	1±0.7	4.6±3.5	6.2±3	156.5±151
	Median	0.1	3.7	0.7	1.5	0	0.1	25.2	20	0.6	1.2	0.7	3.6	5.3	98.6
Total	Mean±SD	1.1±0.3	3.8±3.9	0.8±0.4	1.3±0.8	0.2±0.5	0.2±0.2	77.1±111.5	204.7±231.8	1±1.5	1.2±0.5	1.8±1.5	4.3±2.4	47.4±151.5	82.5±239
	Median	0.3	2.8	0.7	1.1	0	0.1	36.3	103.7	0.5	1.1	1.3	3.8	6.3	24.6
	Range	0.1-10.93	0.19-13.49	0.15-1.88	0.3-3.56	0-2.8	0.03-0.99	6.64-358.69	21.45-996.45	0.19-6.97	0.48-2.21	0.23-6	0.71-11.33	2.11-668.56	6.1-1067.27

Table 2. Toxic element concentrations in hair and nails of the control group (µg/g).

Independent variable	As		Se		Cd		Sn		Cr		Ni		Pb			
	Hair	Nails	Hair	Nails	Hair	Nails	Hair	Nails	Hair	Nails	Hair	Nails	Hair	Nails		
Number of filled teeth	0	Mean±SD	0.1±0	0.2±0	0.3±0	0.85±0	0	0	9.3±1.3	5.2±0.4	0.3±0.1	0.9±0.5	0.6±0.2	0.7±0	2.9±0.6	3.3±1.8
		Median	0.1	0.2	0.3	0.5	0	0	9.3	5.2	0.3	0.9	0.2	0.7	2.9	3.3
	1-3	Mean±SD	0.1±0	3.4±0	1.7±0	1.2±0	0	0	7.7±0	31.7±0	0.2±0	0.6±0	0.4±0	3±0	0.1±0	8.4±0
		Median	0.1	3.4	1.7	1.2	0	0	7.7	31.7	0.2	0.6	0.4	3	0.1	8.4
	3≤	Mean±SD	0.1±0.1	1.1±0.9	0.5±0.2	0.9±0.6	0	0.3±0.4	9±4.4	35.5±34.1	0.2±0.1	3.2±4.7	0.5±0	1.9±1.3	1.9±0.6	7.8±4.7
		Median	0.1	1.2	0.3	0.9	0	0.1	10.2	28.4	0.2	0.5	0.5	1.7	1.9	5.7
Age, year	<35	Mean±SD	0.1±0	1.8±2.3	1±1	0.9±0.4	0.1±0	0.1±0	8±0.5	18.3±19	0.2±0	0.9±0.5	0.6±0.2	1.9±1.6	2.4±1.3	5.2±4.5
		Median	0.1	1.8	1	0.9	0	0	8	18.3	0.2	0.9	0.6	1.9	2.4	5.2
	35≤	Mean±SD	1.2±2.7	3.9±3.9	0.8±0.5	1.3±0.9	0.2±0	0.2±0.2	89.5±123.2	223.6±251.3	1.1±1.7	1.3±0.5	1.9±1.6	4.4±2.5	57.8±170.1	99±268.4
		Median	0.3	2.8	0.7	1.1	0	0.2	36.3	129.8	0.6	1.2	1.5	3.5	6.3	25.1
Em- ploy	<10	Mean±SD	0.1±0	3.4±0	1.7±0	1.2±0	0	0	7.7±0	31.7±0	0.2±0	0.6±0	0.4±0	1.5±0	8.4±0	

Independent variable	As		Se		Cd		Sn		Cr		Ni		Pb		
	Hair	Nails	Hair	Nails	Hair	Nails	Hair	Nails	Hair	Nails	Hair	Nails	Hair	Nails	
10≤	Median	0.1	3.4	1.7	1.2	0	0	7.7	31.7	0.2	0.6	0.4		1.5	8.4
	Mean±SD	0.1±0	0.9±0.8	0.4±0.2	0.8±0.5	0	0	8.9±3.6	27.8±3 1.8	0.2±0.1	2.7±4	0.5±0.1	1.6±1.2	2.3±0.9	6.3±4.8
	Median	0.1	0.7	0.3	0.6	0	0	9.3	16.9	0.2	0.9	0.5	1.2	2.2	5.1
Smoking	Mean±SD	0.2±0	1.9±0	0.8±0	1.5±0	0	0.1±0	12.7±0	5.7±0	0.2±0	8.6±0	0.5±0	3.3±0	1.9±0	28.4±0
	Median	0.2	1.9	0.8	1.5	0	0.1	12.7	5.7	0.2	8.6	0.5	3.3	1.9	28.4
Total	Mean±SD	0.1±0	1.4±1.4	0.2±0.6	1.3±0.8	0	0	8.6±3.2	6.7±4.3	0.2±0.1	2.3±3.6	0.5±0.1	1.9±1.2	2.1±0.8	6.7±4.3
	Median	0.1	1.2	0.4	1.1	0	0	8.4	5.7	0.2	0.6	0.5	1.7	0.19	5.7
	Range	0.07- 0.15	0.18-3.43	0.32- 1.67	0.49- 1.55	0-0.1	0-0.06	4.19-12.74	1.95- 13.2	0.15- 0.33	0.42- 8.59	0.42- 0.74	0.64- 3.27	1.32-3.38	1.95- 13.2

Also, the results showed that the mean Pb concentration values in the hair and nails of the testing group were higher than those in the control group. On the other hand, Pb concentration has increased with age. Besides, Pb concentrations were higher in individuals who had filled teeth (Tables 1 and 2). The elevated levels of Pb could be due to repair activities. However, in the present work, samples with 1 to 3 filled teeth had higher levels of lead in their hair and nails (80.9 and 139.3 $\mu\text{g/g}$, respectively) than cases without any filled teeth (22.6 and 25.6 $\mu\text{g/g}$ for hair and nails, respectively). There was a significant correlation between smoking and lead levels in the nails of case studies, as 156.4 $\mu\text{g/g}$ when they smoked and 109.2 $\mu\text{g/g}$ when not smoking occurred. The major source of exposure the repairers to lead is the solder joints. Therefore, using lead-free solder can help prevent of lead accumulation in the repairer's body (Kumar and Maurya 2022).

3.4. Investigation of the samples

The statistical findings presented in Tables 1 and 2 indicated that the concentrations of arsenic (As) in the analyzed samples exceeded those in the control group. Specifically, the As levels in the hair and nail samples ranged from 3 to 11 times higher than those found in the control group. Although the primary sources of arsenic exposure are typically food and water, smoking was also found to elevate arsenic levels in the samples relative to the control group. Additionally, this study identified a significant correlation between the age of individuals and their duration of employment with their body arsenic levels. As noted in Table 1, individuals over 35 years old and with over 10 years of employment exhibited higher arsenic content compared to those under the age of 35 and with less work experience. As a metalloid, arsenic is recognized as one of the most hazardous elements. In this investigation, the average concentration of arsenic identified in the nails of the participants was 3.8 $\mu\text{g/g}$. Long-term exposure to arsenic can lead to various health issues, such as cardiovascular diseases, peripheral vascular diseases like Blackfoot disease, neurological and neurobehavioral disorders, liver damage, hypertension, and cancer (Das et al. 2012).

3.5. Investigation of Cr in the samples

Compounds of chromium-VI are identified as carcinogenic ions, which raises concerns over the chronic effects of low-level exposure to chromium, both in occupational settings and the environment (KHADEM et al. 2017). In this study, the average concentrations of chromium found were 1 $\mu\text{g/g}$ in hair and 1.2 $\mu\text{g/g}$ in nails. While chromium (VI) compounds are harmful and

recognized as human carcinogens, chromium (III) is necessary for the health of living organisms (Costa and Klein 2006). Inhalation of high concentrations of chromium can lead to irritation of the nasal lining, resulting in symptoms such as nosebleeds, a runny nose, and respiratory issues like asthma, coughing, shortness of breath, or wheezing. Prolonged exposure may lead to liver and kidney damage, circulatory problems, nerve disorders, and skin irritation. The chromium concentrations in hair and nail samples, as well as those in the control group, are detailed in Tables 1 and 2. Given the bioaccumulative properties of chromium, the potential long-term health effects in the various subjects cannot be overlooked. Linyang et al. reported that the mean concentrations of Cr in hair and nail of Chinese people were 3.54 and 6.07 $\mu\text{g/g}$, respectively (Lv et al. 2023).

3.6. Investigation of Ni in the samples

Nickel has been linked to various health issues, including cancer (of the mouth and intestines), depression, heart attacks, hemorrhages, kidney failure, low blood pressure, general malaise, muscle spasms and paralysis, nausea, skin conditions, and vomiting. Our research indicated that nickel levels in hair and nail samples were consistently higher, both spatially and temporally, compared to the control group (see Tables 1 and 2). In our analysis, the average concentration of nickel in hair and nails was measured at 1.8 and 4.3 $\mu\text{g/g}$, respectively. However, it has been reported that the mean concentration of Ni in Chinese people is 2.02 $\mu\text{g/g}$ in hair and 8.81 $\mu\text{g/g}$ in nail samples (Lv et al. 2023). So, we can conclude that the electronic repair job may not affect the human chromium body burden.

3.7. Overall investigation of toxic elements

Our study revealed that in the hair of the tested group, zinc metal with 266.8 $\mu\text{g/g}$ has the highest average value. Wolfsperger et al. (1994) showed that the levels of Pb, Ni, Cr, Co, Cd, and as in the hair of smokers are higher than those of non-smokers (Wolfsperger et al. 1994). Age was the most important variable influencing the Sn, Pb, Ni, As, and Cr content in the hair and nails. In our study the value of toxic metals in the samples less than 35 years old (<35) was less than in the samples taken from older than 35 years. This trend shows that with increasing age, the accumulation of toxic metals in the body increases. Also, in individuals less than 35 years old, Sn, Pb, Ni, As, and Cr content showed a mean concentration of 30.7, 8.1, 1.4, 0.9, 0.4, and 134.2, 20.6, 4, 3.2, 1 $\mu\text{g/g}$ in the hair and nail, respectively. The values of Sn, Pb, Ni, As, and Cr in individuals older than 35 years were 89.5, 57.8, 1.9, 1.2, 1.1, and 223.6, 99, 4.4,

3.9, 1.3 $\mu\text{g/g}$ for hair and nail, respectively. The results of this study showed that when employment time was more than 10 years, the amount of toxic elements increased (Table 1).

Also, Rashed et al. (2007) on different age groups in Sudan and Egypt showed that there was no significant correlation between age groups and element concentrations (Rashed et al. 2007). However, their findings were inconsistent with our study, but Akan et al. found that toxic metal levels increased with the person's age (Akan et al. 2012). The findings reported by Liang et al. (2017) about the hair of men and women of different ages in China showed that although the trend is slightly variable, it can be claimed that with increasing age, the concentration level of toxic elements of cadmium, chromium, lead, arsenic, and mercury increases (Liang et al. 2017). Pereira et al. (2004) found that people of all ages had higher levels of Zn, Cu, Cd, As, and Cr in adults than in children (Pereira et al. 2004). So, the data of researchers has shown that the amount of heavy elements increases with age. The reason for the higher level of elements in older people can be attributed to spending more time around metals, a lack of exercise programs, and lifestyle. Also, the present study is consistent with the results of Mehra and Juneja (2005) in workers aged 18 to 60 years working in high-traffic areas (Mehra and Juneja 2005).

It is important to note that researchers employed various analytical techniques, and given the absence of a standardized protocol for hair analysis, comparisons between different studies should be approached carefully. The elemental concentrations found in biological samples can differ significantly due to factors such as geography, nutrition, and the environment. Nonetheless, studies similar to ours are infrequent; Table 3 presents our findings alongside results from other researchers. There was a lack of available data on Se, Sn, and Ni in the existing literature. Regrettably, the level of As found in our study exceeded that of other reported findings concerning hair. Statistical analyses demonstrated a significant variation in Cd concentration between the samples analyzed and the control group (Table 1). However, smoking tends to elevate Cd levels more in hair than in nails, and in some instances, Cd concentrations in hair have been reported to be lower or comparable. The levels of Cr in our study were also slightly higher than those documented by others, while the amount of Pb was greater than in many cases reported in the literature (Table 3). Unfortunately, there was limited data on nails available for comparison with our findings. Nevertheless, the levels of Pb, Cr, and Cd observed in our study were lower than those indicated in other research.

3.8. Correlation and association between the elements

The body burden of toxic elements may be related to each other. Thus, we investigated the correlation and association between the toxic elements and the selenium content in the samples. To evaluate the level of significance, some elements, including Cr and Se ($\alpha > 0.05$), were used by the Pearson test. Tables 4 and 5 show the correlations of toxic metals in the analyzed samples of hair and nails, respectively, using the Spearman test. Also, pairwise correlation of the toxic elements is presented in Figs. 2 and 3.

As seen in Table 4, there is a positive and significant ($p < 0.05$) correlation between As and Ni, Cd and Ni, Sn and Ni, As, Cd, Ni, and Pb, and Sn and Pb content in the hair samples. According to data from Table 4, a more meaningful and positive correlation was seen in Sn and Ni ($r = 0.836$, $p = 0.000$) and Sn and Pb ($r = 0.686$, $p = 0.001$). It is well known that solder joints containing 60 wt.% Sn and 40 wt.% Pb that, in high temperatures, can evaporate and expose repairers to these toxic metals. So, the best option to remedy is the new technologies eliminating the Pb from the solder, such as those proposed by Wu et al. (2023) (Wu et al. 2023) and low-soldering-temperature joints technology as proposed by Dybel and Pstrus (2023) (Dybel and Pstrus 2023). As Table 5 shows, there are more significant and positive correlations between the toxic elements in the nail samples than in the hair samples. It can be seen that Sn and Pb have a strong correlation together and also with other toxic elements (Cr, Ni, As, and Cd).

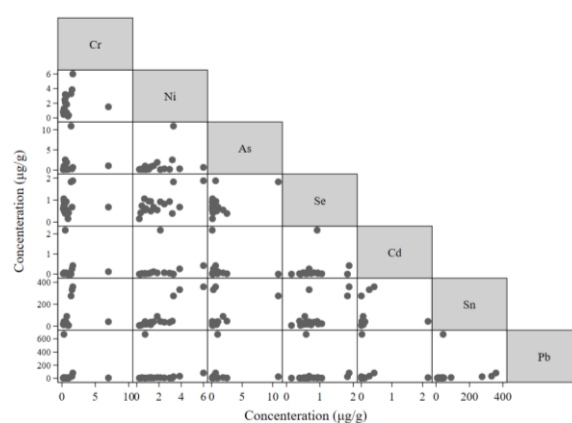


Fig. 2. Pairwise correlation of the toxic elements in the hair samples.

Table 3. Comparison of toxic element concentrations in the hair and nail samples (mean±SD) (µg/g).

Element		As	Se	Cd	Sn	Cr	Ni	Pb
Reference								
Hair	This work	1.1±2.5	0.8±0.4	0.2±0.5	77.1±111	1±1.5	1.8±1.5	47.4±151.5
	(Liang et al. 2017)	0.127±0.078	--	0.071±0.032	--	0.782±0.394	--	1.557±0.77
	(Chojnacka et al. 2005)	0.044±0.11	--	0.114±0.14	--	0.568±1.04	--	1.046±1.39
	(Liang et al. 2017)	0.09±0.11	--	0.23±0.55	--	0.99±2.17	--	7.11±5.92
	(Pereira et al. 2004)	0.834±0.202	--	0.891±0.355	--	0.883±0.193	--	--
	(Y. Li et al. 2020b)	0.423±0.384	--	0.940±1.40	--	1.591±1.16	--	85.3±96.4
	(Nowak and Chmielnicka 2000)	--	--	0.67±0.23	--	--	--	13.77±10.7
	(Hussein Were et al. 2008)	--	--	0.56±2.3	--	0.4±1.34	--	5.7±2.2
Nail	This work	3.8±3.9	1.3±0.8	0.2±0.2	204.7±231	1.2±0.5	4.3±2.4	82.5±239
	(Nowak and Chmielnicka 2000)	--	--	1.2±1.3	--	18.1±42.2	--	11.2±8.1
	(Hussein Were et al. 2008)	--	--	0.62±0.13	--	--	--	34.4±3.5

Table 4. Correlations of toxic metals in the hair of the analyzed samples with the Spearman test.

Toxic metal		Cr	Ni	As	Se	Cd	Sn	Pb
Cr	r	1						
	p							
Ni	r	0.442	1					
	p	0.057						
As	r	0.377	0.486	1				
	p	0.1110	0.034					
Se	r	-0.048	0.399	-0.024	1			
	p	0.844	0.090	0.951				
Cd	r	0.236	0.550	0.015	0.285	1		
	p	0.329	0.014	0.951	0.235			

Toxic metal		Cr	Ni	As	Se	Cd	Sn	Pb
Sn	r	0.443	0.836	0.559	0.373	0.463		
	p	0.057	0.000	0.012	0.114	0.045	1	
Pb	r	0.126	0.517	0.442	0.452	0.439	0.686	
	p	0.605	0.023	0.057	0.052	0.059	0.001	1

Table 5. Correlations of toxic metals in the nails of the analyzed samples using the Spearman test.

Toxic metal		Cr	Ni	As	Se	Cd	Sn	Pb
Cr	r	1						
	p							
Ni	r	0.519	1					
	p	0.022						
As	r	0.664	0.399	1				
	p	0.001	0.090					
Se	r	0.362	0.115	0.907	1			
	p	0.221	0.373	0.028				
Cd	r	0.671	0.532	0.332	0.412	1		
	p	0.001	0.019	0.164	0.199			
Sn	r	0.671	0.715	0.665	0.852	0.676	1	
	p	0.001	0.000	0.001	0.045	0.001		
Pb	r	0.622	0.464	0.463	0.432	0.551	0.501	1
	p	0.004	0.044	0.045	0.191	0.014	0.028	

Table 6. Correlations of Se content with toxic elements in the hair and nails.

Toxic metals		Cr	Ni	As	Cd	Sn	Pb
Se, hair	r	-0.048	0.399	-0.024	0.285	0.373	0.452
	p	0.844	0.090	0.951	0.235	0.114	0.052
Se, nail	r	0.362	0.115	0.907	0.412	0.852	0.432
	p	0.221	0.373	0.028	0.199	0.045	0.191

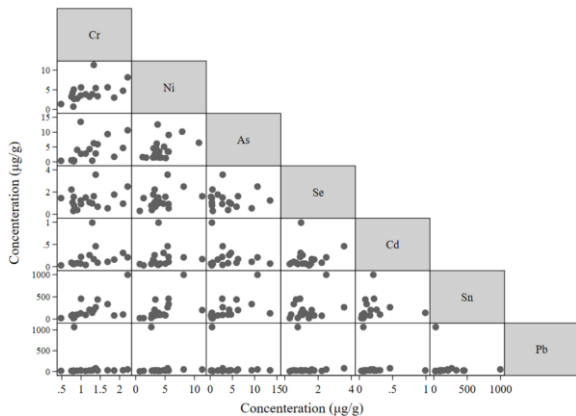


Fig. 3. Pairwise correlation of the toxic elements in the nail samples.

Selenium (Se) is one of the few elements crucial for the typical growth and development of organs. Based on Tables 1 and 2, the selenium levels in the analyzed samples were comparable to or nearly double those found in the nail samples of the control groups. Scientific literature indicates that selenium is a vital element for biological functions in the human body, with a safe range of 60-140 µg/L (Fairweather-Tait et al. 2011; Llorente Ballesteros et al. 2020), and it can enhance the body's immune response (Sun et al. 2023).

As seen in Table 6, we determined that, while there was no notable correlation between the selenium levels in hair samples and other analyzed elements, a strong correlation does exist between the selenium content in nails and the arsenic (As) burden present in nails ($r=0.907$, $p=0.028$). Selenium functions as an antagonist to arsenic and cadmium (Cd), facilitating the sequestration of these elements into biologically inactive complexes by supporting the activity of selenium-dependent antioxidant enzymes (Zwolak 2020).

Dietary habits effectively protect humans from Cd and As occupational pollution (Zhao et al. 2023). Furthermore, the workroom of the repairers should have good ventilation to prevent breathing in indoor toxic vapor from solder joints. Finally, washing hands before eating can prevent the intake of toxic elements by repairers (Eriksen Hammer et al. 2022).

4. Conclusion and Policy Implications

In this study, we examined levels of various harmful substances in the hair and nails of individuals involved in electronic device repairs, compared with a control group. Our goal was to illuminate the potential occupational dangers associated with electronic repair work.

Our results indicated notable differences in the levels of nickel, cadmium, tin, and lead between electronic repair workers and the control group. These findings underscore the occupational hazards encountered by professionals in electronic repair, especially during soldering activities. Soldering, an essential process in the electronics sector, utilizes lead-tin alloy wires and flux, which leads to heightened concentrations of these metals in the biological samples collected from repair technicians. Nevertheless, we did not find significant correlations in the levels of chromium, arsenic, and selenium; particularly, there was no significant difference in selenium levels between the electronic repair subjects and the control group. These findings imply that electronic repair tasks specifically influence the accumulation of certain toxic elements in biological tissues. The concentration ratios of heavy metals varied between hair and nails, with zinc showing the highest levels among the groups studied. This suggests that environmental factors, such as street dust, along with the use of soldering materials, play a significant role in the zinc presence within the samples. The noted relationships between specific toxic elements and electronic repair work emphasize the need for focused safety precautions within this sector.

Furthermore, the identified concentration patterns provide important insights for future studies that aim to assess the relationship between heightened contaminant levels in hair and nails and those found in blood/urine samples, along with potential health implications. These findings can also assist in identifying various exposure routes and regulatory measures intended to protect electronic repair workers while reducing environmental contamination risks. We advise that electronic repair professionals wash their hands with soap before eating and consider a diet rich in selenium, given its ability to convert toxic elements, particularly arsenic, into non-harmful compounds.

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Declarations

Data and code availability

The datasets used and/or analysed during the current study will be available from the corresponding author on reasonable request.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval

The authors declare no ethical issues; the research was carried out in full agreement with ethical standards. Also, this paper is neither under Review nor published elsewhere.

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