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Estimation of Cobalt Level in Blood, Hair and Nails of Leather Industry Workers in Sialkot

Rimsha Imtiaz[1], Saima Ashraf[1], Amina Tahir[1], Asad Shabbir[1], Manahal Sughra[1], Adeel Khalid[1]

[1]Department of Zoology, Zoology Lab, University of Sialkot, Sialkot, Punjab, Pakistan.

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Correspondence to: Saima Ashraf, Department of Zoology, Zoology Lab, University of Sialkot, Sialkot, Punjab, Pakistan.
Email: saima.ashraf@uskt.edu.pk

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ABSTRACT

Pakistan's leather industry, which plays a crucial role in the country's export profits, is confronted with environmental challenges arising from the generation of waste, particularly from tanning procedures that contain high levels of heavy metal pollutants. This study, carried out at the University of Sialkot, Department of Zoology, specifically examines the detrimental consequences of high cobalt exposure among workers. The objective of the experiment was to quantify the concentrations of cobalt in blood, hair, and nail samples obtained from people employed in the Sialkot leather sector. A total of 40 samples were taken from both industrial workers and a control group. Samples of blood, hair, and nails were obtained and processed in the laboratory, then examined using Agilent technology 5110.ICP.OES. The cobalt concentration in the blood of workers in the leather sector is 0.029µg/dl, in hair it is 0.0228µg/g, and in nails it is 0.02375µg/g. By comparison, the levels of cobalt in the control group's blood samples were 0.001µg/dl, in their hair samples were 0.0035µg/g, and in their nail, samples were -0.0008µg/g. These findings emphasize the greater susceptibility to health problems among workers who are exposed to high levels of cobalt in leather industries. This study functions as a vital instrument for raising awareness, highlighting the critical demand for public comprehension of the harmful effects of heavy metals. The findings offer useful information to leather sector workers in Sialkot, assisting in protecting against probable illnesses resulting from cobalt exposure.

INTRODUCTION

The leather industry is the second most significant sector in Pakistan's economy in terms of export earnings. The industry accounts for 5% of the country's GDP [1] and employs over 500,000 individuals [2]. In 2013, it contributed of around 700 million US dollars to Pakistan's exports [3], while in 2014-15, it contributed 724 million US dollars [4]. The leather sector holds considerable economic significance; nonetheless, it is becoming subject to criticism due to the release of toxic waste resulting from leather tanning and processing [5].

Pakistan is renowned in the global market for its exceptional craftsmanship and diverse range of leather goods. Pakistan is ranked 21st in the global market and contributes 6.17% to the production of leather garments, 1.12% to hides and skins, 10.76% to leather gloves, 0.28% to leather footwear, and 0.21% to leather items [6]. The primary leather industries are located in Karachi, Sialkot, Kasur, Lahore, Gujranwala, Multan, and Peshawar [7].

While the leather sector plays a significant part in the country's economy, it also has a detrimental impact on the environment due to the generation of trash. The tanning process generates substantial byproducts and waste in solid, liquid, and gaseous forms, which contribute to pollution through chemical oxygen demand (COD), total dissolved solids (TDS), chlorides, sulphates, and heavy metals [8,9]. The process of leather production entails the use of harmful organic and inorganic compounds, which puts the workers at risk of exposure through several channels such as inhalation, ingestion, and direct contact with the skin [10,11]. Consequently, working in the tannery business has been linked to a range of illnesses due to the presence of biological, toxicological, and carcinogenic substances [12,13]. Tannery workers are exposed to toxic chemicals, which can lead to various difficulties such as irritation of the respiratory tract and eyes, as well as an increased risk of developing cancers such as lung, buccal, pancreatic, and bladder cancer [14].

Sialkot is a densely populated city that is especially susceptible to environmental contamination due to the rapid expansion of urban and industrial sectors in the past decade. This city is renowned worldwide for its production of leather goods, sporting equipment, and surgical instruments. Tanneries in Sialkot are expected to release over 215,036.1 gallons of effluents daily [15]. The discharge of waste from tanneries and enterprises in

Sialkot is a significant contributor to the pollution of soil and water systems in the region [16,17]. Prolonged occupational exposure to heavy metals can lead to various health risks, including asthma, low blood pressure, gastrointestinal diseases, kidney and liver failure, and even cancer. Children are particularly susceptible to these health effects [18,19].

Examples of heavy metals include the elements Cr, Ni, Pb, Cd, and Cu were thoroughly examined because of their long-lasting presence in the environment, widespread occurrence, potential dangers of exposure in both general and occupational settings, inherent toxicity, and ability to cause cancer [20,21].

The detrimental impact of naturally occurring heavy toxic trace metals in soil on human health is widely recognized. Tannery effluents introduce harmful metals into the soil and water, hence increasing the metal concentration in these environments [22]. Chemicals used in the tanning process rely on heavy metals, like as chromium, as significant constituents. Hence, tannery effluents contain a wide range of metals [23].

Heavy metals are introduced into the environment through both natural and human activities. These sources encompass a range of factors, such as natural weathering of the earth's crust, mining activities, soil erosion, industrial discharge, urban runoff, sewage effluents, pest or disease control chemicals applied to plants, fallout from air pollution, and various other sources [24]. While certain individuals may predominantly encounter these pollutants in their work environment, the primary means by which most people are exposed to these harmful substances is through their dietary intake, including food and water. The transmission pathway of heavy metals often adheres to a cyclical sequence: industry, atmosphere, soil, water, food, and human. While the level of concentration plays a role in determining the toxicity and potential harm to human health caused by any contaminant, it is widely recognized that long- term exposure to heavy metals and metalloids at relatively low levels can have negative effects [25,26]. Consequently, there has been a growing apprehension, mostly in industrialized countries, regarding the levels of heavy metals that individuals are exposed to, consume, and absorb. Populations are progressively advocating for a more pristine environment overall, and for diminishing the levels of pollutants that are being transmitted to individuals due to the escalating human activities. In industrialized countries, a practical consequence of this trend has been the implementation of additional laws that are more stringent in nature [27].

Cobalt is commonly encountered in occupational settings due to its extensive use in several industries such as the production of hard metals, grinding, mining, and paint manufacturing [28,29]. Cobalt serves as a mordant in the tanning industry, playing a critical role in facilitating the adherence of dyes to leather. The addition of the mordant enhances the durability against water and light [29]. In addition, cobalt has been utilized for several medical applications, but certain uses have been discontinued over time [30,31].

Georg Brandt is credited with the discovery of cobalt in 1735 and it is a crucial micronutrient found in the human body [32]. This element is classified as a member of the eighth iron-group. Cobalt can exist in a range of oxidation states, ranging from +1 to +5 [33]. Cobalt is abundant in the natural environment and can be generated as a result of human activities [34].

It is found in minor amounts in compounds containing sulphur and arsenic. This element finds extensive use in several industrial applications including as welding, diamond machining, grinding, chemical catalysis, and nuclear power plants [35]. In nuclear reactors, the occurrence of two radioactive isotopes of cobalt, namely 58Co and 60Co, can be attributed to the corrosion-erosion process of cobalt-containing alloys along with other metals. The two types generate photons with great energy, which can be utilized in radiation for combating tumors [36,37].

Cobalt is an essential constituent of vitamin B12 (hydroxocobalamin) and a crucial cofactor in cellular mitosis. In addition, cobalt plays a crucial role in the synthesis of amino acids and certain proteins that contribute to the formation of the myelin sheath in nerve cells [38]. Cobalt also contributes to the synthesis of neurotransmitters, which are essential for proper physiological functioning [39,40]. Cobalt salts enhance the production of erythropoietin, a crucial factor in the stimulation of various stages of erythropoiesis, which is the process of erythrocyte creation in the bone marrow [41]. A lack of cobalt can lead to anemia and reduced thyroid function, increasing the chances of developmental problems and failure in babies [42].

Cobalt is utilized in industrial facilities for the fabrication of alloys and ceramics, as well as for chemical catalysis. In addition, cobalt compounds are utilized in the industrial manufacturing of paints, for example. The color known as Thenard's blue can be achieved by using lacquers on glass and ceramic [43]. Cobalt has been utilized as a pigment in glass, ceramics, and jewelry for millennia due to the distinctive blue hue of certain compounds [44]. The element cobalt was discovered and characterized in the 18th century, and its utilization in industrial contexts began in the early 20th century [45]. The recommended daily Intake of cobalt for humans is 3 µg, with a cobalt content of 0.012 µg [46]. Nevertheless, an excessive amount of this metal can potentially enhance the activity of the thyroid and bone marrow, resulting in an excessive synthesis of red blood cells, fibrosis in the lungs, and the development of asthma [47]. Cobalt salts have long been utilized in medical for treating anemia and in sports as a compelling substitute for conventional blood doping. This metal facilitates the production of erythropoietin, which promotes an increase in the number of red blood cells. In the bloodstream, hence enhancing aerobic fitness.

However, the precise mechanism behind this action remains incompletely understood. Nevertheless, it is established that hypoxia serves as a physiological stimulus for the production of erythropoietin and leads to a reduction in the oxygen levels in the bloodstream [48].

Extensive research has been conducted on the poisonous properties of cobalt and the associated health hazards, through comprehensive investigations on both animals and humans. Several reviews have focused on either a specific exposure setting and its related intake routes, toxicity mechanisms, and clinical consequences [49,50,51], or the impact of Co on a particular physiological system in different Co exposure settings [52,53]. Upon entering the bloodstream, cobalt promptly attaches itself to blood plasma proteins and is then distributed to other tissues. This process leads to the formation of reactive oxygen species, which then inflict detrimental effects on the body as they reach various organs. Certain metallic particles have the capacity to generate significant quantities of oxidizing agents that induce lipid peroxidation. Additionally, it possesses the capacity to generate free radicals that might induce harm to DNA. Co soluble has the capacity to obstruct the calcium channels. It can sometimes lead to the suppression of important enzymes involved in mitochondrial oxidative phosphorylation, the inhibition of thyroid iodinase, and direct harm to cells. The organs susceptible to the harmful effects of cobalt are the liver, lungs, pancreas, cardiovascular system, and kidneys [54].

Nails and hair are biochemically synthesized substances that assimilate metallic elements into their composition as they develop. Hence, the analysis of heavy metal levels in nails and hair is crucial for assessing the effects of environmental pollution on the residents of a community [55,56].

Nails and hair have been proposed as viable indicators of heavy metal presence in contaminated regions. An advantage of using nails and hair as a measure of exposure to heavy metals, as opposed to the typical method of using blood, is that they provide a longer-term reflection of a person's health across several months [57]. In addition, nails and hair offer numerous benefits in terms of monitoring heavy metals, particularly when compared to other biological substances [58,59].

1. They can be acquired without causing harm to the donor.
2. They can be stored for extended durations prior to analysis without undergoing any alterations.
3. Comparatively, nails and hair samples exhibit larger quantities of residues than blood and urine.
4. The ability of hair and nails to absorb metals over long periods of time, indicating at least one year of exposure.

Tannery workers are susceptible to the adverse effects of their frequent exposure to numerous perilous substances and procedures involved in the tanning process. The hazards can be classified into four categories: biological, physical, chemical hazards, and labor accidents [60].

In the tanning process, the outer layer of the hide, known as the epidermis, is initially removed, leaving only the inner layer, called the dermis, which is then converted into leather. In this process, the risk of infection is consistently there, as the hide acts as a conduit for various germs. Microscopic fungal colonies, including Aspergillus niger and Penicillus glaucum, may also exist [61].

Dust is generated during several tanning processes. Chemical particulates may be generated during loading drums used in the processing of hides. Leather dust is generated through mechanical processes. Buffing is the primary contributor to the generation of dust. Tannery dust can contain chemicals, as well as hair pieces, mold, and excrement [62].

Leather tanners who have been exposed to preservatives applied to the hides have been diagnosed with skin illnesses such as eczema and contact (allergic) dermatitis [63,64]. Inhaling chromic acid aerosols released during the chrome- tanning process can cause irritations to the mucous membranes of the throat and nose, as well as perforations in the nasal septum.

Tannery workers face the risk of being exposed to various occupational carcinogens, such as hexavalent chromium salts [65], benzidine-based azo dyes, organic solvents like benzene and formaldehyde, pentachlorophenol, N-nitroso compounds, arsenic, dimethylformamide, and airborne leather dusts. The mentioned exposures have the potential to cause the occurrence of different types of cancers that are specific to certain sites in the body [66,67]. Additionally, there might be other diseases related to one's occupation that can arise from infections and exposure to dusts, chemicals, and physical factors [68]. The purpose of this study was to determine whether prolonged exposure to solvents and chromium compounds had detrimental effects on the respiratory systems and caused health issues in individuals employed in tanneries.

Human nails consist of hard keratins, which are fibrous proteins with high sulfur content [69]. Keratin in fingernails and toenails can form bonds with various elements [70]. The elemental composition of nails exhibits geographical variation, influenced by the natural background circumstances [71]. The duration of exposure indicated by the nail clipping is contingent upon the proximity of the clipping and the pace of nail development. Nail growth can be influenced by various biological parameters, including age, gender, and individual-level features [72,73]. Individuals exhibit varying development rates, but on average, fingernails grow at a rate of 0.1 mm per day. It typically takes approximately 6 months for a regular fingernail to fully grow out [74]. The use of nails to measure metal concentration is not a universally reliable method for monitoring long- term exposure to environmental pollutants. This is because the concentration of metals in nails reflects their average level in the human body over a period of 12-18 months. Several studies [75,76,77].

Research Objectives

The primary goal of this investigation is as follows:

- **i.** To evaluate the health conditions of leather industry workers.
- **ii.** To measure the level of cobalt in blood, hair, and nail samples of workers of

Sialkot Leather Industries

Workers in Sialkot's leather industry encounter a range of occupational risks, such as the possibility of being exposed to cobalt through leather dyes. Limited research exists on cobalt levels in biological samples and associated health effects, highlighting the need for a comprehensive study. The lack of information in this area gives rise to significant worries over the safety and well-being of leather workers in Sialkot. Workers in Sialkot's leather sector may be at risk for health problems because of cobalt exposure. It is crucial to comprehend the possible health risks associated with occupational exposure to cobalt and its compounds, as well as the detection of cobalt in the blood, hair, and nails of leather industry workers in Sialkot. Cobalt is an important component for cell division and is found in vitamin B12 (hydroxocobalamin). However, excessive exposure to cobalt can have detrimental consequences on one's health.

MATERIALS AND METHODS

This research was carried out at many Sialkot large-scale leather factories. Sialkot is located between 32º and 37º North latitude and 73ºC, 59E to 75ºE longitude. Sialkot's leather sector is concentrated in five areas, most of which are in the north and northwest suburbs of the city. Sialkot is home to several licensed leather industry. There are several leather production facilities located inside the city. A single leather industry was selected from each center. For the sample process, a total of five distinct sectors were selected at different places. The workers in the leather business were asked for their approval first. They answered questionnaires on their individual characteristics (e.g., gender, age, lifestyle, food, health circumstances etc.).

Cobalt concentrations in blood, hair, and nail samples were examined in order to investigate metal exposure at work. 40 samples from various leather industry personnel were gathered. As a control group, samples of 40 university students were collected. Samples of blood were taken using heparinized vials. Using a pair of sterile scissors that can be cleaned with ethanol, the hair samples were extracted from the head. The participants were instructed to thoroughly wash their hands with medicated soap and distilled water, then pat dry with a fresh towel or piece of tissue paper to eliminate any potential external contamination. Nail clippers made of stainless steel that are also useful for cutting hair were employed.

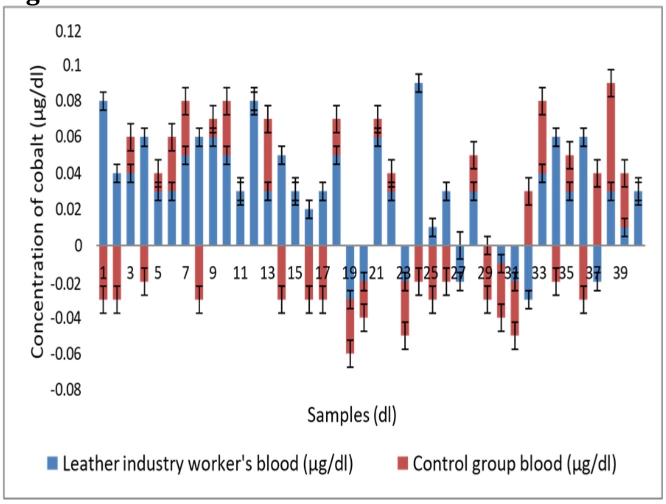
First, a 500µl pipettor setting was made, and then the pipettor was used to draw blood. A beaker was filled with the blood samples that had been taken. The blood samples were then placed in beakers and 1 ml of hydrogen peroxide was added to the particular beaker containing the blood samples, along with 2 ml of nitric acid. After that, the beakers were covered with aluminum foil and kept for 10 minutes at room temperature. The samples were placed on a magnetic stirrer after 10 minutes had passed. For 120 minutes, the temperature was held at sixty-five degrees Celsius. The sample was put onto a wooden plate within this time limit, when the solution started to boil after 30 minutes. After that, the aluminum foil was taken out of each beaker. Two milliliters of nitric acid and a few drops of hydrogen peroxide were added to that mixture. Once more, the samples were put on a hot plate that had been heated to 85 degrees Celsius and the solution covered with foil. Boiling was reached for the solutions, giving them a thick, honey-like appearance or a white dry substance. Once the consistency was as desired, 10 milliliters of a 1-molar solution were added. To guarantee complete purification, the solution was then filtered twice [78].

Using a pipettor, add 630µl of nitric acid to a beaker containing 100 ml of distilled water to create a 1 molar solution. To eliminate any external contamination, ethanol-washed, sterilized stainless-steel scissors were used to cut hair samples from each patient. A neutral solvent was then utilized. In order to facilitate future examination, these hair samples were labelled and kept in plastic bags. Initially, three rounds of de-ionized water washing were performed on hair and nail samples. Following a first acetone wash to get rid of any foreign contaminants, a second wash with de-ionized water was performed. To remove all of the moisture, the hair and nail samples' water content was dried for an hour at 110 °C in an oven [79]. In sterile crucibles, samples of hair and nails were collected. A standard procedure was used to assess the amount of cobalt in samples of hair and nails. A 50 ml beaker was filled with each dried hair and nail sample. Following a 2:0.5 digestion, each sample was allowed to rest at room temperature for 12 hours. Nitric and hydrochloric acids were then added to each sample. Once the solution was clear or had a light yellowish tint, the samples were cooked on a magnetic stirrer between 160 and 180 degrees Celsius. Subsequently, the mixture was let to reach room temperature. The samples were cooled before being filtered to get rid of any impurities. Each sample was then transferred to a 25ml volumetric flask and 10ml of de-ionized water was added. Following that, the centrifuge tubes containing the solution were refrigerated [79].

An inductively coupled plasma optical emission spectrometry (ICP-OES) device (Optima 2100 DV, Agilent technologies, Australia, 2018) was used to analyze the amount of cobalt in blood, nail, and hair samples. Calibration curves were created utilizing five distinct concentrations (0.01, 0.05, 0.1, 0.5, and 1 mg/L) of the multi- element standard solution (Multi-Element Calibration Standard 3) in order to achieve the calibration of the device. The operating conditions of the device were: radiofrequency power of 1300 W; nebulizing flow of 0.8 L/min; and plasma flow of 15 L/min. Cobalt emission intensity measurements were made at 238.892 nm wavelength. The HNO3 and H2O2 solution was used as a blank sample by diluting it to the same concentration as during the sample preparation stage. Every measurement had the blank sample deducted after analysis.

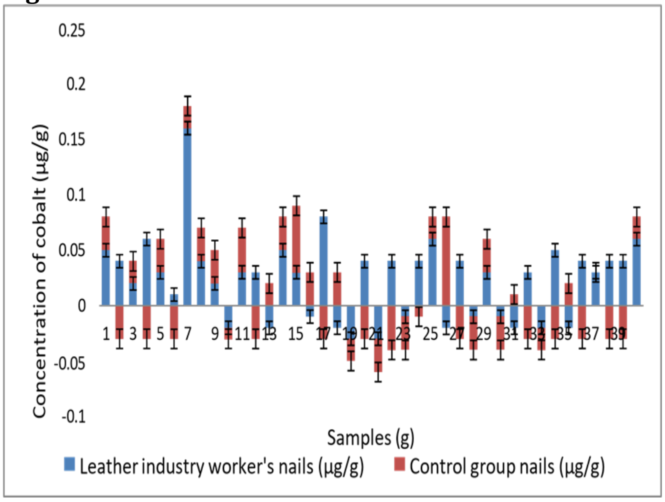
RESULTS

Figure 1



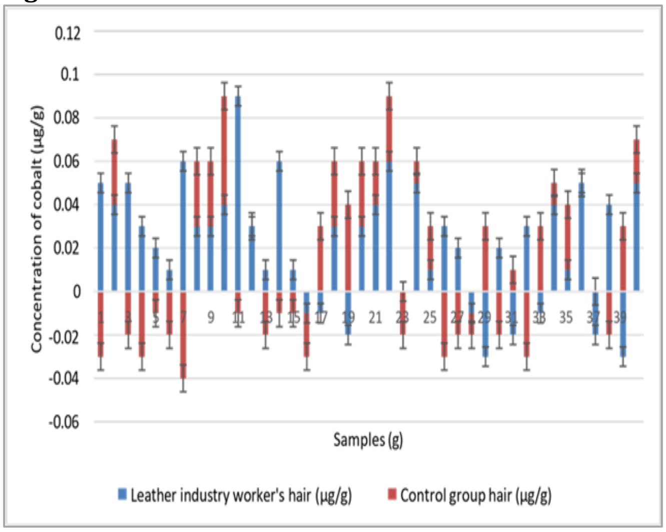
Variations in cobalt levels were found in 40 blood samples from leather industry workers and 40 samples from a control group. The sample from the 24th worker in the leather sector had the highest cobalt content i.e,0.09µg/dl, while two other blood samples of leather industry had amounts of 0.08µg/dl. The 19th and 32nd worker samples from the leather industry had the lowest amounts, at -0.03µg/dl.

Figure 2



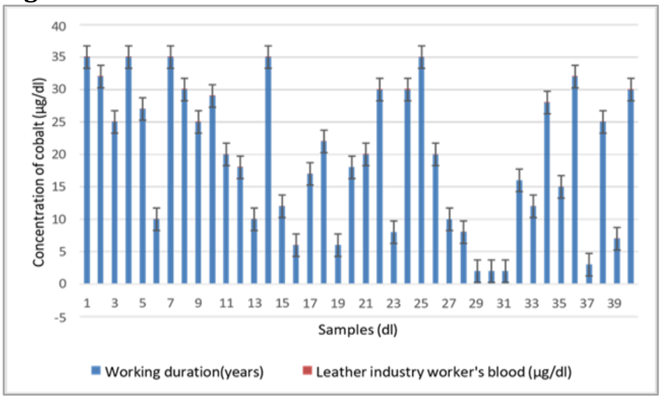
The graphical illustration clearly shows that workers in the leather sector had higher levels of cobalt concentration than those in the control group. Most remarkably, nail samples were used to measure cobalt levels. It is noteworthy that the nail sample taken from the 7th worker, which had a cobalt content of 0.16µg/g at its peak, showed this. It's also important to note that, with a cobalt content of 0.08µg/g, the 17th sample had the second lowest concentration.

Figure 3



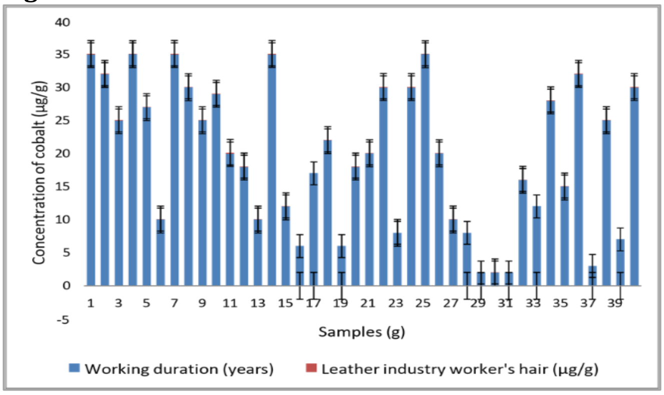
The variation in cobalt concentration between the control group and leather industry workers is clearly seen in the graphical depiction. In particular, compared to the control group, workers had noticeably greater cobalt concentration. Analysis of the hair samples shows this variance. With regard to cobalt content, the hair sample from the eleventh worker had the highest value, at 0.09µg/g.

Figure 4



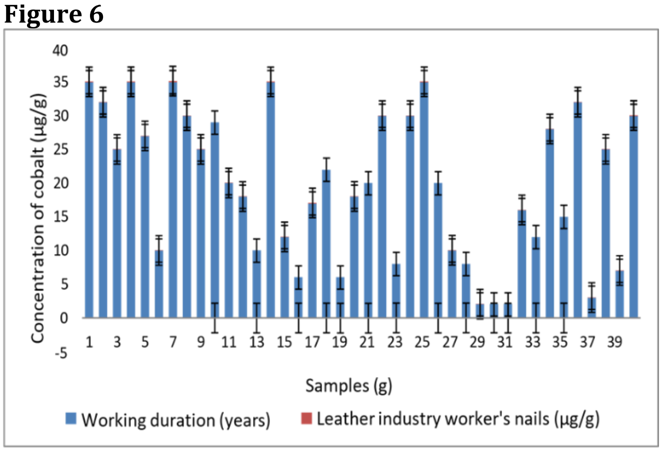
According to the study's findings, cobalt's impact on leather industry workers seems to be quite negligible when considering the length of their employment. With a cobalt content of 0.08µg/dl, Sample 1 exhibits a greater concentration after 35 years of exposure to the tannery environment. Interestingly, Sample 24, who worked in the tannery for 30 years, had the highest concentration i.e,0.09µg/dl. Analysis of Sample 24 has been justified due to the observed pattern, which indicates that the maximum cobalt content was obtained after a lengthy exposure of 30 years.

Figure 5



According to the study's findings, there is a significant difference in the effect of cobalt on workers in the leather sector based on how long they have worked there. Sample 14 had worked in a tannery for 35 years, and in the context of this investigation, its cobalt content was rather higher at 0.06µg/g. Sample 11, on the other hand, had the highest cobalt content at 0.09µg/g after 20 years of service.

Figure 6



The results of the study indicate that, when compared to the length of time they have worked, the effects of cobalt on workers in the leather sector seem to be somewhat mild. In particular, Sample 7, which was examined in this study during a 35-year period at the tannery, has the highest cobalt content, at 0.16 µg/g. Sample 17, on the other hand, shows the second-highest concentration, measured at 0.08 µg/g, despite having worked in the tannery for 17 years.

Table 1
Descriptive statistics of cobalt concentration found in the samples of blood, nails, and hair of workers of leather industries

Variables	Maximum value	Minimum value	Mean	Median	Standard Deviation
Blood	0.09	-0.03	0.029	0.03	0.0316
Hair	0.09	-0.03	0.0228	0.03	0.0282
Nails	0.16	-0.03	0.02375	0.03	0.03733

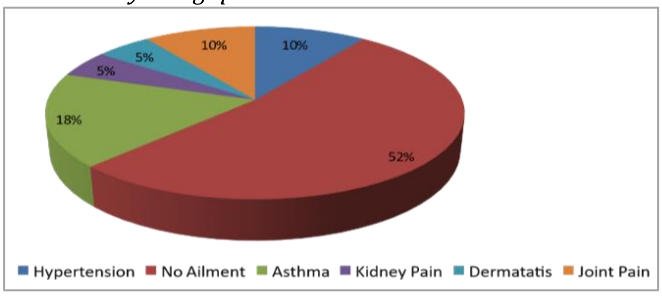
The findings of this investigation show that the blood levels of cobalt in Sialkot tannery workers are considerably greater than those in samples of their hair and nails. In Sialkot, blood samples from leather industry workers had the highest documented quantity of cobalt at 0.09µg/dl. The minimum concentration of cobalt in hair was 0.03µg/g, and in nails, it was -0.03µg/g. According to the independent sample t-test, there was a significant difference ($p<0.05$) in the mean values of the blood, hair, and nail samples.

Table 2
Descriptive statistics of cobalt concentration found in the samples of blood, nails, and hair of control group

Variables	Maximum value	Minimum value	Mean	Median	Standard Deviation
Blood	0.06	-0.03	-0.001	0	0.02706
Hair	0.05	-0.04	-0.0035	0	0.0247
Nails	0.08	-0.04	-0.0008	-0.01	0.0313

The control group's hair had much less cobalt than their blood or nail samples, according to the study's findings. Blood samples from the control group showed maximum cobalt content of 0.06µg/dl in Sialkot, Pakistan. The lowest amount of cobalt found in hair and nails was -0.04µg/g and -0.04µg/g, respectively. The blood, hair, and nail sample means were all highly significant ($p<0.05$), according to the independent sample t-test.

Figure 7
Percentage of severe diseases among the workers of leather industries by using questionnaire



When the percentages of common disorders among tannery workers were calculated, it was discovered that 5% had dermatitis, 10% had joint pain, 10% had hypertension, 18% had asthma, 5% had kidney problems, and 52% did not have any ailment.

DISCUSSION

The objective of this research is to evaluate the health status of employees in the leather sector and quantify the concentrations of cobalt in blood, hair, and nail samples collected from workers in the Sialkot leather industries. This research is motivated by the necessity to comprehend the repercussions of cobalt exposure on the well-being of individuals involved in the leather industry.

Prior studies have documented those workers in leather sectors globally are at danger of being exposed to high amounts of heavy metals, which can lead to oxidative stress and potential health hazards [80]. This study was carried out in Sialkot, which is the largest exporter of leather products in Asia. The study focused on monitoring the levels of heavy metals, specifically cobalt (Co), in three different biometrics. The study also investigated the industrial sources of these heavy metals, the accompanying oxidative stress, and the potential health concerns faced by workers in the leather industry. The study revealed that the exposed workers had higher concentrations of harmful heavy metals (namely Cobalt) and lower levels of necessary elements (Zinc, Manganese, Iron, and Copper) compared to the control group. The presence of high levels of heavy metals in the indoor dust of leather businesses causes significant health hazards to the workers who are exposed to it [81].

Heavy metals produce oxidative stress by causing an imbalance in the production of reactive oxygen species (ROS) [82]. Reactive oxygen species (ROS) play a natural role in combating xenobiotics, such as heavy metals, within the body. Additionally, they are engaged in cell signaling pathways [83]. This study aimed to identify the cobalt levels in the blood, nails, and hair samples of 40 people employed in the leather sector in Sialkot. A control group of 40 persons was also included for comparison. An evaluation was conducted to examine the impacts of cobalt exposure, wherein persons suffering from illness were classified into distinct groups according to their age and level of expertise.

The data gathering process involved administering a questionnaire to individuals in the leather industry population. The results indicated that 5% of the respondents reported experiencing kidney pain, 5% reported dermatitis, 10% reported hypertension, 10% reported joint pain, and 18% reported asthma. It is important to mention that there is a connection between cobalt exposure and occupational asthma.

A previous study presented a series of cases on asthma generated by cobalt [84]. Cobalt has been found to cause harmful effects on skin cells [85,86,87]. Cobalt can cause contact dermatosis in industrial settings [88], and exposure to radiocobalt in the nuclear industry can lead to external contamination through skin contact [89]. The involvement of DNA damage and interaction with DNA repair systems in cobalt toxicity, either directly or indirectly, has been suggested [90].

An investigation based on age showed a decreased occurrence of the disease in the 20-30 age range (5%), which could be related to a strong immune system. Nevertheless, there was a gradual rise in the prevalence of diseases as individuals became older, reaching its highest point at 23% among those aged 41-50. This pattern implies a potential connection between decreasing immunity and the observed increase in diseases.

Subsequent examination considered individuals' work experience, which uncovered a correlation between more professional experience and the occurrence of skin, respiratory problems, and joint pain. There is evidence of a direct relationship between age, work experience, and the effects of cobalt exposure. The findings indicate that younger individuals possess a more robust immune system, whereas individuals with extended cobalt exposure demonstrate increased vulnerability to health problems. This underscores the significance of age and job experience when evaluating the health consequences of heavy metal exposure.

The previously reported that Cd and Pb are likely to be contaminated due to their extended half-lives in the human body, which are 10-40 years and 2 months to 20 years, respectively. Hence, the heightened levels of pollution and strong associations shown in this study can be attributed to the increased utilization of these metals in insecticides, batteries, glazed ceramics, fuels, PVC paints, plating, and smelting procedures [91].

The cobalt concentrations in the blood, hair, and nails of leather industry workers (0.029, 0.0228, and 0.02375, respectively) are substantially different from the values observed in the control group (-0.001, 0.0035, and -0.0008). The data reveal that there is a larger concentration of cobalt among industry workers, which may be correlated with their increased health problems compared to the relatively healthy control group.

Upon analyzing Figure 7, it is evident that the age group of 45-50 years has the greatest cobalt concentration in blood, measuring 0.09μg/dl. Figure 9 and Figure11 demonstrate the highest levels of cobalt in hair (0.09μg/g) and nails (0.16μg/g) across certain age groups. This underscores the notable difference between cobalt concentrations in the bodies of leather industry workers and the average population. Table 1 demonstrates that those who have worked for 25-35 years had a larger occurrence of disease (23%) compared to those with 15-24 years of experience (7%), when considering the length of their work experience. Table 4 demonstrates a direct relationship between longer periods of labor and increased levels of cobalt in hair samples. This suggests that the type of job, safety precautions, and the number of hours worked are important factors in determining cobalt exposure and its impact on health. According to Table 6, the cobalt concentrations in the blood, hair, and nails of leather industry workers are 0.029±0.0316μg/dl, 0.0228±0.0282μg/g, and 0.02375±0.03733μg/g, respectively. The research highlights that the accumulation of cobalt is contingent upon the duration of workers' employment. Individuals who have been employed for duration of 1-35 years have blood levels that range from a high of 0.09μg/dl to a low of -0.03μg/dl. The average blood level is 0.029±0.0316 μg/dl. The concentration of nails ranges from a minimum of -0.03μg/g to a maximum of 0.16μg/g, with an average value of 0.02375±0.03733μg/g. The hair samples show a maximum concentration of 0.09μg/g, a lowest concentration of -0.03μg/g, and an average concentration of (0.0228±0.0282μg/g).

The statistical analysis in Table 6 reveals a substantial disparity (p=0.00002) in blood levels between those employed in the leather sector (0.029±0.0316μg/dl) and the control group (-0.001±0.02706μg/dl). Similarly, there is a notable distinction (p=0.0017) in the levels of hair between workers (0.0228±0.0282μg/g) and the control group (0.0035±0.02476μg/g). Additionally, nails also demonstrate a significant difference (p=0.0021) between workers (0.02375±0.03733μg/g) and the control group (-0.0008±0.03133μg/g). The research highlights that the control group samples exhibited mostly negative values, with a few exceptions displaying higher cobalt contents. This observation highlights the body's innate ability to control cobalt levels, keeping them within the normal physiological range. The somewhat elevated levels observed in certain control group samples may suggest the inherent ability of the body to regulate cobalt, a crucial metal that plays key roles in the human body.

While the study's scope is restricted to 40 samples in Sialkot, investigating cobalt and other heavy metals has the potential to deepen our comprehension of their impacts. The high levels of cobalt seen in the blood, hair, and nails of workers can be explained by their occupation, which involves frequent contact to heavy metals, particularly cobalt-based dyes. This research is crucial for addressing workers' health concerns and underscores the necessity of implementing preventive measures in the leather sector.

CONCLUSION

The study highlights cobalt as a serious occupational danger for industrial workers by decisively demonstrating a link between increased cobalt levels and working exposure. Between the blood of leather industry workers (0.029±0.0316 μg/dl) and the control group (-0.001±0.02706 μg/dl), there was a significant and statistically significant difference (p=0.00002) in the cobalt concentrations. For nails (p=0.0021) and hair (p=0.0017), comparable statistically significant changes were found. The levels of cobalt in the blood, hair, and nail samples of industrial workers were significantly greater than those in the control group, indicating a strong inter-correlation. This highlights the detrimental effects of these metals on industry workers' health and provides information on possible dependencies and compounding effects of heavy metal exposure in the leather sector. The study recommends that prompt protective measures be taken, stressing the need of wearing gloves, masks, and protective jackets while working as well as imposing dietary restrictions, periodic health examinations, and ensuring enough ventilation in the workplace.

Although nails accumulate less blood than hair, blood and hair are suggested as useful biological markers for assessing cobalt exposure. The study emphasizes how critical it is that the general people be made aware of the risks involved in careers in the leather sector. Workers in the workplace need to know this information in order to take the appropriate safety measures and shield themselves from illnesses brought on by cobalt exposure.

REFERENCES

1. Ghafoor, A., Aslam, M., & Rasool, S. (2012). Determinants of leather goods exports: A case of Pakistan. *Journal of Business & Economics*, *4*(2), 256.
2. Siddiqui, A., Uroos, A., & Nadeem, F. (2016). *Sectoral competitiveness and value chain analysis: leather gloves value chain analysis in Pakistan. Trade development authority of Pakistan*.
3. Shahab, S., & Mahmood, M. T. (2013). Comparative advantage of leather industry in Pakistan with selected Asian economies. *International Journal of Economics and Financial Issues*, *3*(1), 133-139. https://dergipark.org.tr/en/pub/ijefi/issue/31956/351887
4. Junaid, M., Hashmi, M. Z., Tang, Y., Malik, R. N., & Pei, D. (2017). Potential health risk of heavy metals in the leather manufacturing industries in Sialkot, Pakistan. *Scientific Reports*, *7*(1). https://doi.org/10.1038/s41598-017-09075-7
5. Gómez, V., Pasamontes, A., & Callao, M. (2006). Factorial design for optimising chromium determination in tanning wastewater. *Microchemical Journal*, *83*(2), 98-104. https://doi.org/10.1016/j.microc.2006.03.009
6. Mohmand, J., Eqani, S. A., Fasola, M., Alamdar, A., Mustafa, I., Ali, N., Liu, L., Peng, S., & Shen, H. (2015). Human exposure to toxic metals via contaminated dust: Bio-accumulation trends and their potential risk estimation. *Chemosphere*, *132*, 142-151. https://doi.org/10.1016/j.chemosphere.2015.03.004
7. Stern, F. B., Beaumont, J. J., Halperin, W. E., Murthy, L. I., Hills, B. W., & Fajen, J. M. (1987). Mortality of chrome leather tannery workers and chemical exposures in tanneries. *Scandinavian Journal of Work, Environment & Health*, *13*(2), 108-117. https://doi.org/10.5271/sjweh.2073
8. Song, Z. (2000). Sedimentation of tannery wastewater. *Water Research*, *34*(7), 2171-2176. https://doi.org/10.1016/s0043-1354(99)00358-9
9. Qadir, A., Malik, R. N., & Husain, S. Z. (2007). Spatio-temporal variations in water quality of nullah aik-tributary of the river Chenab, Pakistan. *Environmental Monitoring and Assessment*, *140*(1-3), 43-59. https://doi.org/10.1007/s10661-007-9846-4
10. Ali, Z., Malik, R. N., & Qadir, A. (2013). Heavy metals distribution and risk assessment in soils affected by tannery effluents. *Chemistry and Ecology*, *29*(8), 676-692. https://doi.org/10.1080/02757540.2013.810728
11. Malik, R. N., Jadoon, W. A., & Husain, S. Z. (2009). Metal contamination of surface soils of industrial city Sialkot, Pakistan: A multivariate and GIS approach. *Environmental Geochemistry and Health*, *32*(3), 179-191. https://doi.org/10.1007/s10653-009-9274-1
12. ATSDR, 2000. (Agency for Toxic Substances and Disease Registry), Toxicological Profile of Chromium. US Department of Health and Human Service, Public Health, ATSDR.
13. Jiménez-Rodríguez, A., Durán-Barrantes, M., Borja, R., Sánchez, E., Colmenarejo, M., & Raposo, F. (2009). Heavy metals removal from acid mine drainage water using biogenic hydrogen sulphide and effluent from anaerobic treatment: Effect of pH. *Journal of Hazardous Materials*, *165*(1-3), 759-765. https://doi.org/10.1016/j.jhazmat.2008.10.053
14. Jomova, K., & Valko, M. (2011). Advances in metal-induced oxidative stress and human disease. *Toxicology*, *283*(2-3), 65-87. https://doi.org/10.1016/j.tox.2011.03.001
15. Burgos, S., Tenorio, M., Zapata, P., Cáceres, D. D., Klarian, J., Alvarez, N., Oviedo, R., Toro-Campos, R., Claudio, L., & Iglesias, V. (2017). Cognitive performance among cohorts of children exposed to a waste disposal site containing heavy metals in Chile. International Journal of Environmental Health Research, 27(2), 117-125. https://doi.org/10.1080/09603123.2017.1292494
16. Gil, F., Hernández, A. F., Márquez, C., Femia, P., Olmedo, P., López-Guarnido, O., & Pla, A. (2011). Biomonitorization of cadmium, chromium, manganese, nickel and lead in whole blood, urine, axillary hair and saliva in an occupationally exposed population. *Science of The Total Environment*, *409*(6), 1172-1180. https://doi.org/10.1016/j.scitotenv.2010.11.033
17. McIntyre, T. (2003). Phytoremediation of heavy metals from soils. *Advances in Biochemical Engineering/Biotechnology*, 97-123. https://doi.org/10.1007/3-540-45991-x 4
18. Nabi, G., Ashraf, M., & Aslam, M. R. (2001). Heavy-metal contamination of agricultural soils irrigated with industrial effluents. *Science Technology and Development*, *20*.
19. Ming-Ho, Y. (2005). Environmental Toxicology: Biological and Health Effects of Pollutants, Chap. 12, CRC Press LLC, ISBN 1-56670-670-2, 2nd Edition, BocaRaton, USA.
20. Agency for Toxic Substance and Disease Registry (ATSDR). (2003a). Toxicological Profile for Arsenic U.S. Department of Health and Humans Services, Public Health Humans Services, Centers for Diseases Control. Atlanta.
21. Agency for Toxic Substance and Disease Registry (ATSDR). (2003b). Toxicological Profile for Mercury U.S. Department of Health and Humans Services, Public Health Humans Services, Centers for Diseases Control. Atlanta.
22. Agency for Toxic Substance and Disease Registry (ATSDR). (2007). Toxicological Profile for Lead U.S. Department of Health and Humans Services, Public Health Humans Services, Centers for Diseases Control. Atlanta.
23. Castro-González, M., & Méndez-Armenta, M. (2008). Heavy metals: Implications associated to fish consumption. *Environmental Toxicology and Pharmacology*, *26*(3), 263-271. https://doi.org/10.1016/j.etap.2008.06.001
24. European Commission (2006). Regulation (EC) No 1881/2006. JO L364, 20.12.06, pp. 5-24. ExtoxNet. (2003) Cadmium contamination of food, http://ace.orst.edu/info/extoxnet/faqs/foodcon/cadmium.htm2003
25. Figueroa B., E. (2008). Are more restrictive food cadmium standards justifiable health safety measures or opportunistic barriers to trade? An answer from economics and public health. *Science of The Total Environment*, *389*(1), 1-9. https://doi.org/10.1016/j.scitotenv.2007.08.015
26. Barceloux, D. G., & Barceloux, D. (1999). Cobalt. *Journal of Toxicology: Clinical Toxicology*, *37*(2), 201-216. https://doi.org/10.1081/clt-100102420

27. Agency for Toxic Substance and Disease Registry (ATSDR). (2008). Draft. Toxicological Profile for Cadmium U.S. Department of Health and Humans Services, Public Health Humans Services, Centers for Diseases Control. Atlanta.
28. International Agency for Research on Cancer (IARC), (2006). Working Group on the Evaluation of Carcinogenic Risk to Humans. Cobalt in hard metals and cobalt sulfate, gallium arsenide, indium phosphide and vanadium pentoxide.
29. Pajdowski L (1982): Chemia ogólna. Wydawnictwo NaukowePWN, Warszawa.
30. Ortega, R., Bresson, C., Fraysse, A., Sandre, C., Devès, G., Gombert, C., Tabarant, M., Bleuet, P., Seznec, H., Simionovici, A., Moretto, P., & Moulin, C. (2009). Cobalt distribution in keratinocyte cells indicates nuclear and perinuclear accumulation and interaction with magnesium and zinc homeostasis. *Toxicology Letters*, *188*(1), 26-32. https://doi.org/10.1016/j.toxlet.2009.02.024
31. Roesems, G., Hoet, P., Dinsdale, D., Demedts, M., & Nemery, B. (2000). In vitro cytotoxicity of various forms of Cobalt for rat alveolar macrophages and type II Pneumocytes. *Toxicology and Applied Pharmacology*, *162*(1), 2-9. https://doi.org/10.1006/taap.1999.8824
32. Gault, N., Sandre, C., Poncy, J., Moulin, C., Lefaix, J., & Bresson, C. (2010). Cobalt toxicity: Chemical and radiological combined effects on HaCaT keratinocyte cell line. *Toxicology in Vitro*, *24*(1), 92-98. https://doi.org/10.1016/j.tiv.2009.08.027
33. Bresson, C., Lamouroux, C., Sandre, C., Tabarant, M., Gault, N., Poncy, J., Lefaix, J., Den Auwer, C., Spezia, R., Gaigeot, M., Ansoborlo, E., Mounicou, S., Fraysse, A., Deves, G., Bacquart, T., Seznec, H., Pouthier, T., Moretto, P., Ortega, R., … Moulin, C. (2008). An interdisciplinary approach to investigate the impact of Cobalt in a human keratinocyte cell line. *Biochimie*, *88*(11), 1619-1629. https://doi.org/10.1016/j.biochi.2006.09.003
34. Battaglia, V., Compagnone, A., Bandino, A., Bragadin, M., Rossi, C. A., Zanetti, F., Colombatto, S., Grillo, M. A., & Toninello, A. (2009). Cobalt induces oxidative stress in isolated liver mitochondria responsible for permeability transition and intrinsic apoptosis in hepatocyte primary cultures. *The International Journal of Biochemistry & Cell Biology*, *41*(3), 586-594. https://doi.org/10.1016/j.biocel.2008.07.012
35. Simonsen, L. O., Brown, A. M., Harbak, H., Kristensen, B. I., & Bennekou, P. (2011). Cobalt uptake and binding in human red blood cells. *Blood Cells, Molecules, and Diseases*, *46*(4), 266-276. https://doi.org/10.1016/j.bcmd.2011.02.009
36. Simonsen, L. O., Harbak, H., & Bennekou, P. (2012). Cobalt metabolism and toxicology—A brief update. *Science of The Total Environment*, *432*, 210-215. https://doi.org/10.1016/j.scitotenv.2012.06.009
37. Patel, E., Lynch, C., Ruff, V., & Reynolds, M. (2012). Co-exposure to nickel and Cobalt chloride enhances cytotoxicity and oxidative stress in human lung epithelial cells. *Toxicology and Applied Pharmacology*, *258*(3), 367-375. https://doi.org/10.1016/j.taap.2011.11.019
38. Karovic, O., Tonazzini, I., Rebola, N., Edström, E., Lövdahl, C., Fredholm, B. B., & Daré, E. (2007). undefined. *Biochemical Pharmacology*, *73*(5), 694-708. https://doi.org/10.1016/j.bcp.2006.11.008
39. Lombaert, N., Lison, D., Van Hummelen, P., & Kirsch-Volders, M. (2008). In vitro expression of hard metal dust (WC–Co) — responsive genes in human peripheral blood mononucleated cells. *Toxicology and Applied Pharmacology*, *227*(2), 299-312. https://doi.org/10.1016/j.taap.2007.11.002
40. Campbell, J. R., & Estey, M. P. (2012). Metal release from hip prostheses: Cobalt and chromium toxicity and the role of the clinical laboratory. *Clinical Chemistry and Laboratory Medicine (CCLM)*, *51*(1), 213-220. https://doi.org/10.1515/cclm-2012-0492
41. Borowska, S., & Brzóska, M. M. (2015). Metals in cosmetics: Implications for human health. *Journal of Applied Toxicology*, *35*(6), 551-572. https://doi.org/10.1002/jat.3129
42. Delaunay, C., Petit, I., Learmonth, I., Oger, P., & Vendittoli, P. (2010). Metal-on-metal bearings total hip arthroplasty: The Cobalt and chromium ions release concern. *Orthopaedics & Traumatology: Surgery & Research*, *96*(8), 894-904. https://doi.org/10.1016/j.otsr.2010.05.008
43. Daniel, C. R., Piraccini, B. M., & Tosti, A. (2004). The nail and hair in forensic science. *Journal of the American Academy of Dermatology*, *50*(2), 258-261. https://doi.org/10.1016/j.jaad.2003.06.008
44. Devlin, J. J., Pomerleau, A. C., Brent, J., Morgan, B. W., Deitchman, S., & Schwartz, M. (2013). Clinical features, testing, and management of patients with suspected prosthetic hip-associated Cobalt toxicity: A systematic review of cases. *Journal of Medical Toxicology*, *9*(4), 405-415. https://doi.org/10.1007/s13181-013-0320-0
45. Pizon, A. F., Abesamis, M., King, A. M., & Menke, N. (2013). Prosthetic hip-associated Cobalt toxicity. *Journal of Medical Toxicology*, *9*(4), 416-417. https://doi.org/10.1007/s13181-013-0321-z
46. Bocca, B., Pino, A., Alimonti, A., & Forte, G. (2014). Toxic metals contained in cosmetics: A status report. *Regulatory Toxicology and Pharmacology*, *68*(3), 447-467. https://doi.org/10.1016/j.yrtph.2014.02.003
47. Bradberry, S. M., Wilkinson, J. M., & Ferner, R. E. (2014). Systemic toxicity related to metal hip prostheses. *Clinical Toxicology*, *52*(8), 837-847. https://doi.org/10.3109/15563650.2014.944977
48. Christensen, J. M., & Poulsen, O. M. (1994). A 1982–1992 surveillance programme on Danish pottery painters. Biological levels and health effects following exposure to soluble or insoluble Cobalt compounds in Cobalt blue dyes. *Science of The Total Environment*, *150*(1-3), 95-104. https://doi.org/10.1016/0048-9697(94)90134-1
49. Gessner, B. D., Steck, T., Woelber, E., & Tower, S. S. (2019). A systematic review of systemic Cobaltism after wear or corrosion of Chrome-Cobalt hip implants. *Journal of Patient Safety*, *15*(2), 97-104. https://doi.org/10.1097/pts.0000000000000220
50. Catalani, S., Rizzetti, M., Padovani, A., & Apostoli, P. (2011). Neurotoxicity of Cobalt. *Human & Experimental Toxicology*, *31*(5), 421-437. https://doi.org/10.1177/0960327111414280
51. De Boeck, M., Kirsch-Volders, M., & Lison, D. (2004). Corrigendum to "Cobalt and antimony: Genotoxicity and carcinogenicity" [Mutat. Res. 533 (2003) 135–152]. *Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis*, *548*(1-2), 127-128. https://doi.org/10.1016/j.mrfmmm.2004.02.001
52. Beyersmann, D., & Hartwig, A. (1992). The genetic toxicology of Cobalt. *Toxicology and Applied Pharmacology*, *115*(1), 137-145. https://doi.org/10.1016/0041-008x(92)90377-5
53. Garner, L. A. (2004). Contact dermatitis to metals. *Dermatologic Therapy*, *17*(4), 321-327. https://doi.org/10.1111/j.1396-0296.2004.04034.x
54. Jarvis, J. Q., Hammond, E., Meier, R., & Robinson, C. (1992). Cobalt cardiomyopathy: a report of two cases from mineral assay laboratories and a review of the literature. *Journal of occupational medicine*, 620-626.

55. Sheikh, I. (2016). Cobalt poisoning: A comprehensive review of the literature. *Journal of Medical Toxicology and Clinical Forensic Medicine*, *2*(2). https://doi.org/10.21767/2471-9641.100017
56. Paustenbach, D. J., Tvermoes, B. E., Unice, K. M., Finley, B. L., & Kerger, B. D. (2013). undefined. *Critical Reviews in Toxicology*, *43*(4), 316-362. https://doi.org/10.3109/10408444.2013.779633
57. Finley, B. L., Unice, K. M., Kerger, B. D., Otani, J. M., Paustenbach, D. J., Galbraith, D. A., & Tvermoes, B. E. (2013). 31-Day study of Cobalt(II) chloride ingestion in humans: Pharmacokinetics and clinical effects. *Journal of Toxicology and Environmental Health, Part A*, *76*(21), 1210-1224. https://doi.org/10.1080/15287394.2013.848391
58. Nowak, B., & Chmielnicka, J. (2000). Relationship of lead and cadmium to essential elements in hair, teeth, and nails of environmentally exposed people. *Ecotoxicology and Environmental Safety*, *46*(3), 265-274. https://doi.org/10.1006/eesa.2000.1921
59. Mortada, W. I., Sobh, M. A., El-Defrawy, M. M., & Farahat, S. E. (2002). Reference intervals of cadmium, lead, and mercury in blood, urine, hair, and nails among residents in Mansoura city, Nile delta, Egypt. *Environmental Research*, *90*(2), 104-110. https://doi.org/10.1006/enrs.2002.4396
60. Rodushkin, I., & Axelsson, M. D. (2000). Application of double focusing sector field ICP-MS for multielemental characterization of human hair and nails. Part I. Analytical methodology. *Science of The Total Environment*, *250*(1-3), 83-100. https://doi.org/10.1016/s0048-9697(00)00369-7
61. Slotnick, M. J., Nriagu, J. O., Johnson, M. M., Linder, A. M., Savoie, K. L., Jamil, H. J., & Hammad, A. S. (2005). Profiles of trace elements in toenails of Arab-Americans in the Detroit area, Michigan. Biological Trace Element Research, 107(2), 113-126. https://doi.org/10.1385/bter:107:2:113
62. Ashraf, W., Jaffar, M., & Mohammad, D. (1994). Trace metal contamination study on scalp hair of occupationally exposed workers. *Bulletin of Environmental Contamination and Toxicology*, *53*(4). https://doi.org/10.1007/bf00199020
63. Pereira, R., Ribeiro, R., & Gonçalves, F. (2004). Scalp hair analysis as a tool in assessing human exposure to heavy metals (S. Domingos mine, Portugal). *Science of The Total Environment*, *327*(1-3), 81-92. https://doi.org/10.1016/j.scitotenv.2004.01.017
64. Gulson, B. L. (1996). Nails: Concern over their use in lead exposure assessment. *Science of The Total Environment*, *177*(1-3), 323-327. https://doi.org/10.1016/0048-9697(95)04896-0
65. Bencze, K. (1990). What contribution can be made to biological monitoring by hair analysis? *Fresenius' Journal of Analytical Chemistry*, *337*(8), 867-876. https://doi.org/10.1007/bf00323164
66. Agency for Toxic Substances and Disease Registry (ATSDR). 2001. Agency for Toxic Substances and Disease Registry. Hair Analysis Panel Discussion: Exploring the State of the Science. June 12–13. Summary Report. Agency for Toxic Substances and Disease Registry, Division of Health Assessment and Consultation and Division of Health Education and Promotion. Atlanta, Georgia, 2001
67. Baker DB: Tanning and leather finishing; Stellman JM (eds.): Encyclopaedia of Occupational Health and Safety, 4th edn. Vol III. Geneva, ILO, 1998, pp.88.2–88.7
68. Ory, F., Rahman, F., Katagade, V., Shukla, A., & Burdorf, A. (1997). Respiratory disorders, skin complaints, and low-back trouble among tannery workers in Kanpur, India. *AIHAJ*, *58*(10), 732-739. https://doi.org/10.1080/15428119708984791 8894(1997)058<0732:rdscal>2.0.co;2
69. Stern, F. B. (2003). Mortality among chrome leather tannery workers: An update. *American Journal of Industrial Medicine*, *44*(2), 197-206. https://doi.org/10.1002/ajim.10242
70. Braid PE: Fur industry; Stellman JM (eds.): Encyclopaedia of Occupational Health and Safety, 4th edn. Vol III. Geneva, ILO, 1998, pp.88.2–88.7
71. Rothman, K. J. (1993). Methodologic frontiers in environmental epidemiology. *Environmental Health Perspectives*, *101*(suppl 4), 19-21. https://doi.org/10.1289/ehp.93101s419
72. Fleckman, P. (1997). Basic science of the nail unit. *Nails: therapy, diagnosis, surgery*, *2*, 37-54.
73. Hayashi, M., Yamamoto, K., Yoshimura, M., Hayashi, H., & Shitara, A. (1993). Cadmium, lead, and zinc concentrations in human fingernails. *Bulletin of Environmental Contamination and Toxicology*, *50*(4). https://doi.org/10.1007/bf00191244
74. Chen, K. B., Amarasiriwardena, C. J., & Christiani, D. C. (1999). Determination of total arsenic concentrations in nails by inductively coupled plasma mass spectrometry. *Biological Trace Element Research*, *67*(2), 109-125. https://doi.org/10.1007/bf02784067
75. Adewale, M., Taiwo, Tunde., Hassan, Ifeoluwa., A. Adeoye, Ganiyat., A. Adekoya, Olamide, E. Tayo., Deborah, O. Ogunsola, Mutiat., K. Babawale, Onyinyechukwu., T. Isichei, Sukurat., O. Olayinka., (2023). Department of Environmental Management and Toxicology, Federal University of Agriculture,Abeokuta, PMB 2240, Nigeria Volume 5, September, 100087.
76. Afridi, H. I., Kazi, T. G., Kazi, A. G., Shah, F., Wadhwa, S. K., Kolachi, N. F., Shah, A. Q., Baig, J. A., & Kazi, N. (2011). Levels of arsenic, cadmium, lead, manganese and zinc in biological samples of paralysed steel mill workers with related to controls. *Biological Trace Element Research*, *144*(1-3), 164-182. https://doi.org/10.1007/s12011-011-9063-4
77. Afzal, M., Shabir, G., Iqbal, S., Mustafa, T., Khan, Q. M., & Khalid, Z. M. (2013). Assessment of heavy metal contamination in soil and groundwater at leather industrial area of Kasur, Pakistan. *CLEAN – Soil, Air, Water*, *42*(8), 1133-1139. https://doi.org/10.1002/clen.201100715
78. Agency for Toxic Substance and Disease Registry (ATSDR). (2008). Draft. Toxicological Profile for Cadmium U.S. Department of Health and Humans Services, Public Health Humans Services, Centers for Diseases Control. Atlanta.
79. Agency for Toxicological Substances and Disease Registry (ATSDR). Toxicological profile for cobalt. U.S. Department of Health and Human Services, Public Health Service. 2004.
80. Ali, Z., Malik, R. N., & Qadir, A. (2013). Heavy metals distribution and risk assessment in soils affected by tannery effluents. *Chemistry and Ecology*, *29*(8), 676-692. https://doi.org/10.1080/02757540.2013.810728
81. Ashraf, I., Ahmad, F., Sharif, A., Altaf, A. R., & Teng, H. (2021). Heavy metals assessment in water, soil, vegetables and their associated health risks via consumption of vegetables, district Kasur, Pakistan. *SN Applied Sciences*, *3*(5). https://doi.org/10.1007/s42452-021-04547-y
82. Athavale, P., Shum, K., Chen, Y., Agius, R., Cherry, N., & Gawkrodger, D. (2007). Occupational dermatitis related to chromium and Cobalt: Experience of dermatologists (EPIDERM) and occupational physicians (OPRA) in the U.K. over an 11-year period (1993?2004). *British Journal of Dermatology*, *157*(3), 518-522. https://doi.org/10.1111/j.1365-2133.2007.08030.x

83. Brosin, A., Wolf, V., Mattheus, A., & Heise, H. (1997). Use of XTT-assay to assess the cytotoxicity of different surfactants and metal salts in human keratinocytes (HaCaT). A feasible method for in vitro testing of skin irritants. *Acta Dermato-Venereologica*, *77*(1), 26-28. https://doi.org/10.2340/0001555577026028
84. KORNHAUSER, C., WRÓBEL, K., WRÓBEL, K., MALACARA, J. M., NAVA, L. E., GÓMEZ, L., & GONZÁLEZ, R. (2002). Possible adverse effect of chromium in occupational exposure of tannery workers. *INDUSTRIAL HEALTH*, *40*(2), 207-213. https://doi.org/10.2486/indhealth.40.207
85. Chattopadhyay, A., & Jervis, R. E. (1974). Hair as an indicator of multielement exposure of population groups. In *Trace substances in environmental health. VIII*. https://inis.iaea.org/records/jzwy7-9ge25
86. Chaudhari, P. R., Gupta, R., Gajghate, D. G., & Wate, S. R. (2011). Heavy metal pollution of ambient air in Nagpur
91. DeCaprio, A. P. (1997). Biomarkers: coming of age for environmental health and risk assessment. *Environmental Science & Technology*, *31*(7), 1837-1848. https://doi.org/10.1021/es960920a
city. *Environmental Monitoring and Assessment*, *184*(4), 2487-2496. https://doi.org/10.1007/s10661-011-2133-4
87. Junaid, M., Hashmi, M. Z., Tang, Y., Malik, R. N., & Pei, D. (2017). Potential health risk of heavy metals in the leather manufacturing industries in Sialkot, Pakistan. *Scientific Reports*, *7*(1). https://doi.org/10.1038/s41598-017-09075-7
88. Halliwell, B. (2011). Free radicals and antioxidants – quo vadis? *Trends in Pharmacological Sciences*, *32*(3), 125-130. https://doi.org/10.1016/j.tips.2010.12.002
89. Sauni, R., Linna, A., Oksa, P., Nordman, H., Tuppurainen, M., & Uitti, J. (2010). Cobalt asthma -- a case series from a Cobalt plant. *Occupational Medicine*, *60*(4), 301-306. https://doi.org/10.1093/occmed/kqq023
90. Sapota, A., & Darago, A. (2011). Kobalt i jego związki nieorganiczne–w przeliczeniu na Co. *Podstawy i Metody Oceny Środowiska Pracy*, (3 (69), 47-94.