Biological and Clinical Sciences Research Journal
eISSN: 2708-2261; pISSN: 2958-4728
www.bcsrj.com
DOI: https://doi.org/10.54112/bcsrj.v6i7.1908
*Biol. Clin. Sci. Res. J., Volume 6(7), **2025**: 1908*
Original Research Article

Hair and Nail Lead Concentrations in Leather-Industry Workers Compared with Community Controls: A Cross-Sectional Study

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(Received, 04th April 2025, Accepted 18th July 2025, Published 31st July 2025)

Abstract: *Occupational exposure to lead (Pb) remains a serious global public health concern, particularly in leather manufacturing, where workers are chronically exposed to toxic substances. Hair and nail matrices serve as reliable biomarkers for assessing long-term lead accumulation.* ***Objective:*** *To compare hair and nail lead concentrations between leather-industry workers and community controls in Sialkot, Pakistan.* ***Methods:*** *This analytical cross-sectional study was conducted on 80 adults, including 40 leather workers and 40 age- and sex-matched non-exposed controls. Hair and nail samples were collected, washed, decontaminated, and digested with nitric and hydrochloric acids before analysis with inductively coupled plasma–optical emission spectrometry (ICP-OES). Mean concentrations (µg/g) were compared using two-sided statistical significance testing, with p<0.05 considered significant.* ***Results:*** *Hair lead levels were significantly higher among workers than controls (0.3300 ± 0.6589 vs −0.0462 ± 0.0543 µg/g; p=0.0056). Similarly, nail lead concentrations were elevated in workers compared with controls (0.2662 ± 0.6521 vs −0.0240 ± 0.1002 µg/g; p=0.0067). The highest hair and nail lead concentrations were observed in workers aged 51–53 years (2.06 µg/g) and 55–60 years (2.91 µg/g), respectively. Lead concentrations showed a positive correlation with years of employment, indicating progressive bioaccumulation.* ***Conclusion:*** *Leather-industry workers exhibited significantly higher hair and nail lead concentrations compared with community controls, reflecting chronic occupational exposure. These findings emphasize the importance of routine biomonitoring, adequate protective measures, and enforcement of stricter occupational health and safety regulations in Pakistan's leather industry.*

Keywords: Bioaccumulation, Hair, Lead, Nails, Occupational Exposure, Pakistan

[***How to Cite:*** Tahir A, Ashraf S, Awais M, Esha UT, Ashraf S, Shahzadi A, Khalid A. Hair and nail lead concentrations in leather-industry workers compared with community controls: a cross-sectional study. *Biol. Clin. Sci. Res. J.*, **2025;** 6(7): 62-65. doi: https://doi.org/10.54112/bcsrj.v6i7.1908

Introduction

Lead (Pb) exposure remains a significant public health concern, particularly for workers in industries handling or processing this toxic metal. The leather industry, associated with hazardous materials, has come under increased scrutiny due to the potential health risks faced by workers, including elevated lead concentrations in biological samples such as hair and nails. Lead, a heavy metal, is known for its neurotoxic effects and is linked with various chronic health conditions, underscoring the need for thorough assessments of occupational exposure levels in such environments.

Numerous studies have documented the severe health impacts of occupational lead exposure. For instance, Yadav et al. found that lead exposure is significantly associated with conditions such as hypertension and poor pulmonary function in workers, reinforcing the connection between high blood lead levels (BLL) and adverse health outcomes (1). In another study, Yu et al. noted that occupational lead exposure may contribute to chronic kidney disease (CKD), particularly in individuals with comorbidities such as hypertension or (2) diabetes. Abdraboh's research on workers in spray painting activities indicated significant health hazards associated with lead exposure, emphasizing the need for effective monitoring in various industrial contexts (3).

Biomonitoring is a crucial component of occupational health, with evidence showing that hair lead concentration can serve as a reliable biological indicator of both environmental and occupational exposures. A systematic review by Mariem et al. established that elevated lead levels in hair reflect higher workplace exposure levels, suggesting that hair analysis can be an effective surveillance tool (4). This is supported by research indicating a correlation between environmental lead exposure and its presence in biological samples, affirming the use of hair as an indicator of chronic exposure (5). Recent studies have reported significantly higher lead concentrations in workers compared to community controls, reinforcing the importance of ongoing biological monitoring (6).

Regulatory frameworks play a critical role; the management of lead exposure in the workplace must focus on significantly reducing allowable BLLs to protect workers from cumulative and chronic health risks (7). Recent research emphasizes the need for enhanced workplace practices and regulations to mitigate the adverse health effects of lead exposure, particularly in industries like leather production, where exposure can be persistent (8).

In the context of Pakistan, investigating lead concentrations in leather industry workers is particularly important. The country's leather industry, which employs a significant workforce, often operates with limited health regulations and oversight. This lack of regulation poses risks for workers who may unknowingly be exposed to hazardous materials, including lead (9). Furthermore, the findings from such studies could advocate for improved occupational health policies and better living conditions for affected communities, ultimately contributing to public health initiatives aimed at reducing lead exposure risks in vulnerable populations (10).

Methodology

This analytical cross-sectional study was conducted in Sialkot, Pakistan, with all laboratory work performed at the Department of Zoology, University of Sialkot. We enrolled 80 adults: 40 leather-industry workers and 40 community controls with no occupational heavy-metal exposure, after written informed consent. Sampling was carried out specifically for keratinized matrices, scalp hair, and nails preserved in clean plastic bags and transported to the laboratory for processing. Ethical approval was obtained from the University of Sialkot Institutional Review Board, and procedures adhered to the Helsinki Declaration.

Hair was cut from the scalp using sterilized scissors rinsed with ethanol; nail samples were clipped using clean tools. To minimize exogenous contamination, both hair and nail samples underwent a standardized decontamination protocol: triple rinse with de-ionized water, a single acetone rinse, and a final rinse with de-ionized water, followed by oven-drying at 110 °C for one hour to remove residual moisture. Dried specimens were then transferred to 50-mL glass beakers for acid digestion.

Matrix digestion used a mixed-acid method appropriate for keratinized tissues. Each hair or nail sample was digested with nitric acid (HNO_3) and hydrochloric acid (HCl) in a 2:0.5 ratio and left to stand at room temperature for 12 hours. Samples were subsequently heated on a magnetic stirrer at 160–180 °C until the solution became clear or pale yellow, allowed to cool to room temperature, and filtered to remove particulates. A reagent blank (HNO_3/H_2O_2 diluted to the same concentrations used in sample preparation) was processed in parallel and subtracted from each measurement to correct for background.

Lead concentrations in hair and nail digests were quantified using inductively coupled plasma–optical emission spectrometry (ICP-OES; Agilent), monitoring 340.458 nm. External calibration employed Multi-Element Calibration Standard 3, with five calibration levels (0.01, 0.05, 0.10, 0.50, and 1.00 mg/L) to generate calibration curves before sample runs. Instrument performance and blank agreement were verified before reporting. Data were summarized as mean ± standard error (SE); between-group differences (workers vs. controls) were evaluated with two-sided significance set at $p < 0.05$.

Results

Eighty participants were analyzed (40 leather-industry workers; 40 controls). Workers had significantly higher hair and nail lead than controls. Hair lead: 0.3300 ± 0.6589 µg/g vs −0.0462 ± 0.0543 µg/g (p = 0.0056). Nail lead: 0.2662 ± 0.6521 µg/g vs −0.0240 ± 0.1002 µg/g (p = 0.0067). (Table and Figure 1). Among workers, the highest observed hair lead was 2.06 µg/g in the 51–53 years group, and the highest observed nail lead was 2.91 µg/g in the 55–60 years group. Small negative values in controls reflect blank subtraction near the detection limit. In leather-industry workers, hair and nail lead concentrations increased with greater years of employment (1–35 years), indicating bioaccumulation; numeric ranges for hair and nail are not tabulated in the text, but the upward trajectories are evident in Figure 3 and are supported by the presence of long-tenure categories (e.g., 25–35 years) in the plotted cohort.

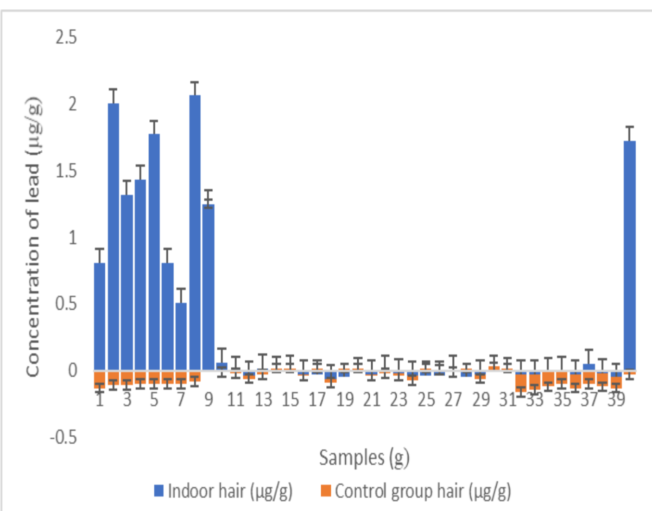
Table 1. Hair and nail lead concentration by group

Matrix	Group	n	Mean ± SE	Unit	p-value
Hair	Workers	40	0.3300 ± 0.6589	µg/g	0.0056
Hair	Controls	40	−0.0462 ± 0.0543	µg/g	—
Nail	Workers	40	0.2662 ± 0.6521	µg/g	0.0067
Nail	Controls	40	−0.0240 ± 0.1002	µg/g	—

Table 2. Peak observed hair and nail lead by age category (workers)

Matrix	Age category with peak	Peak value
Hair	51–53 years	2.06 µg/g
Nail	55–60 years	2.91 µg/g

Methods note: Measurements were expressed as mean ± SE with a blank run subtracted from each reading.



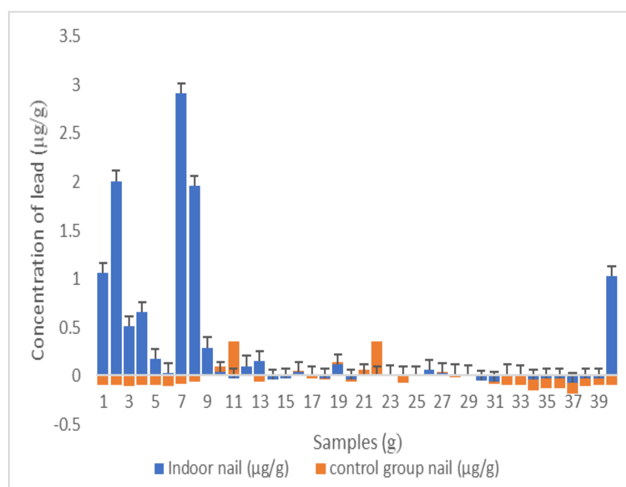


Fig. 1 Lead concentrations (µg/g wet weight) in the blood, hair, and nail samples of workers in the leather industry

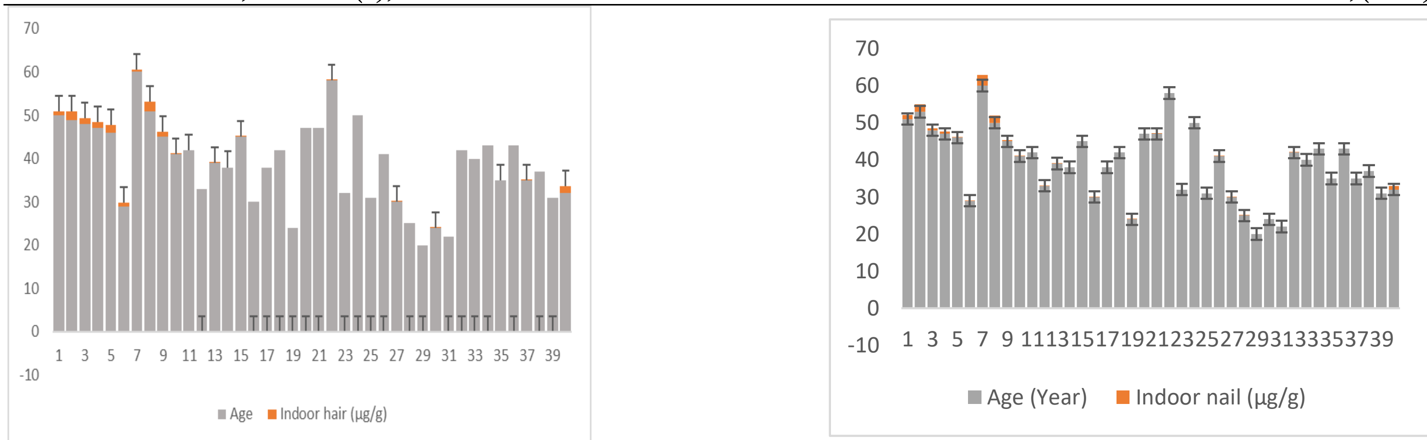


Figure 2: The association between the concentration of lead in hair and nails, of leather industry workers and their age

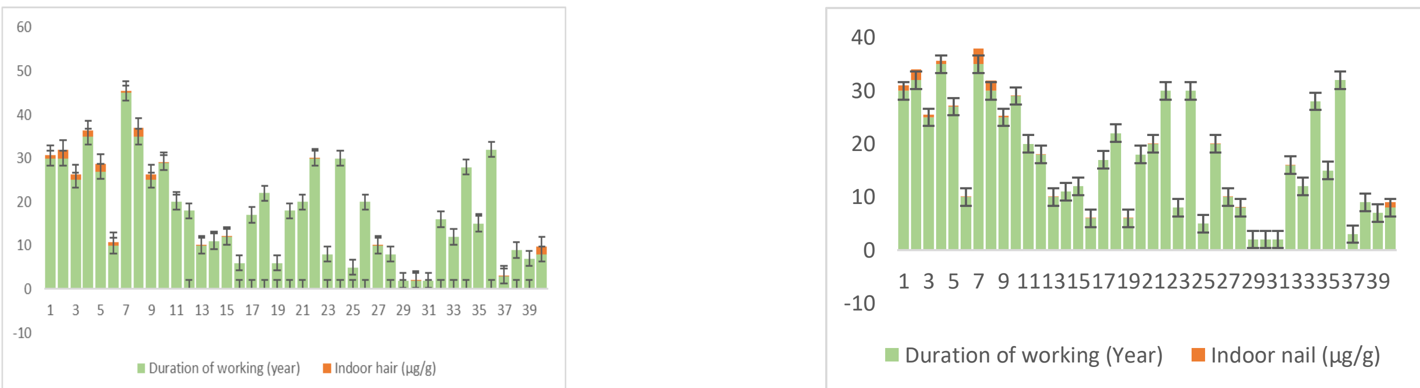


Fig.3 The association between the concentration of lead in blood, hair, and nail of leather industry workers with their working years

Discussion

The results of our study demonstrate that leather-industry workers exhibit significantly higher concentrations of lead in both hair and nails compared to protected community controls. Specifically, the mean hair lead concentration among workers was elevated considerably at 0.3300 ± 0.6589 µg/g, compared to control levels of −0.0462 ± 0.0543 µg/g ($p = 0.0056$). Similarly, nail lead concentrations in workers averaged 0.2662 ± 0.6521 µg/g versus −0.0240 ± 0.1002 µg/g in controls ($p = 0.0067$). Significant findings include the observation of peak hair lead levels (2.06 µg/g) in workers aged 51–53 and peak nail lead levels (2.91 µg/g) among those aged 55–60. Furthermore, increased lead concentrations in hair and nails were correlated with years of employment, suggesting a bioaccumulation effect over time.

Our findings resonate with those reported by Hussain et al., who analyzed trace metal accumulation among different age groups in Pakistan, revealing similar trends of elevated lead levels in workers exposed to hazardous environments (11). Their outcomes corroborate the occupational hazards associated with prolonged metal exposure, which parallels the biological indicators we've measured in workers' hair and nails.

In relation to lead specifically, prior research has established hair and nails as effective biomarkers for assessing lead exposure. For instance, Bansal emphasizes that nails and hair accumulate metals over extended periods, reflecting average levels of exposure to toxic substances (12). This supports our results showing the bioaccumulation of lead in the keratinized tissues of leather-industry workers.

Further reinforcing our findings, Firkey et al. noted variability in lead retention and concentrations in hair and nails, emphasizing their utility as indicators for environmental exposure (13). Their work highlights how sample collection methods and preparation can influence results, underscoring the importance of methodological rigor when interpreting lead levels in biological samples.

Our observation of higher lead concentrations in older age groups (51-60 years) among workers aligns with findings from Cobo-Golpe et al., who reported a correlation between chronic exposure and increasing concentrations of various toxic metals in hair and nails that often intensify with age (14). This evidence suggests that prolonged occupational exposure not only heightens lead levels but also raises concerns regarding cumulative health effects, including neurotoxicity and other systemic impacts noted in previous studies (15).

Additionally, the presence of negative lead values in controls, reflective of blanks near detection limits, speaks to the critical importance of comparative analysis with adequately matched populations to account for environmental background levels, as emphasized by Hussain et al. in their exploration of comparable matrices (11).

Furthermore, the findings shed light on potential health implications for Pakistani leather workers, a demographic facing significant occupational hazards. The need for occupational health initiatives, including regular monitoring of lead levels, educational interventions, and improved workplace safety protocols, is critical given the evidence linking lead exposure to adverse health outcomes detailed in several recent studies (11,12). The impacts of such exposure are particularly alarming in developing countries like Pakistan, where regulatory oversight in labor-intensive industries, including leather, may be limited (11).

Thus, our study contributes to the growing body of literature highlighting the hazardous conditions faced by leather industry workers in Pakistan. The significant bioaccumulation of lead seen in biological samples such as hair and nails not only underscores occupational risks but also emphasizes the urgent need for health interventions and tighter regulation in industries characterized by hazardous exposures.

Conclusion

Lead concentrations in hair and nails were markedly higher among leather-industry workers compared to controls, with levels rising alongside years of employment. These findings confirm occupational bioaccumulation and call for targeted preventive measures, periodic exposure assessments, and enforcement of occupational health standards in Pakistan's leather sector.

Declarations

Data Availability statement
All data generated or analysed during the study are included in the manuscript.
Ethics approval and consent to participate
Approved by the department concerned. (IRBEC-24)
Consent for publication
Approved
Funding
Not applicable

Conflict of interest

The authors declared the absence of a conflict of interest.

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MA
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Study Design, manuscript review, critical input.
SA
Manuscript drafting, Study Design,
AS & AK
Conception of Study, Development of Research Methodology Design,

All authors reviewed the results and approved the final version of the manuscript. They are also accountable for the integrity of the study.

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