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Assessment of lead exposure using hair and nails as biopsy materials

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Abstract:
Lead (Pb) levels in fingernails and hair samples of occupationally exposed and unexposed subjects were determined by atomic absorption spectrophotometry. Pb hair and Pb nail concentrations in occupationally exposed subjects of 11-20 to 51-60 years of age ranged between 1.07 to 173.44 µg/g and 10.34 to 125.69µg/g respectively. A progressive increase in Pb concentrations with longer exposure was evident.Significant levels of lead were found in fingernails and hair of subjects with mental stress, respiratory problems and hypertension . A correlation ($p < 0.05$) existed between lead (Pb) concentrations in samples of occupationally exposed versus unexposed individuals. Overall, Pb concentrations were significantly higher in hair of smokers .

Keywords: *Atomic Absorption Spectrophotometry, biological monitoring, lead, exposure*

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I. Introduction:

The rapid expansion of industrial society, driven by intensive mining and mineral processing, has led to significant issues related to environment specifically metal pollution. Although humans have processed and recovered metals since ancient times, only over the past century have these practices transformed into large-scale industrial operations with high resource demands. Nevertheless, the recognition of risks of heavy metal pollution for humans has emerged relatively recently. Metal contamination arises from two primary sources: anthropogenic activities and natural geological processes. The widespread release of toxic metals—through industrial emissions and leachates from hazardous waste—has prompted global initiatives, including sample surveys and bio monitoring programs. Under the guidance of international agencies, collaborative research efforts helped in ascertaining heavy metal exposure in humans. By systematically sampling biological media such as urine, blood, fat, saliva, feces, hair, nails, kidney, liver, and bone, researchers can better understand the relationship between environmental exposure and health outcomes. Scalp hair, in particular, has been shown to reflect long-term trends in trace metal levels.

Lead (Pb), similar to cadmium, is a non-essential and highly toxic metal for humans. It acts as a cumulative poison and potent neurotoxin, representing a classic example of a multimedia environmental pollutant due to its widespread occurrence in air, water, soil, and food. Within the human body, lead exhibits a strong affinity for macromolecules, particularly proteins containing sulfhydryl (-SH) groups, such as metallothionein rich in cysteine residues. In addition to vehicular and industrial emissions, several industrial and manufacturing processes contribute substantially to environmental Pb contamination. Metallic lead is widely employed in the fabrication of pipes, cisterns, acid containers, bullets, shot, linotype metal, and in alloys with antimony, tin, and copper for making storage battery plates and cable sheathing. Glass and rubber industries also utilize lead[1-2]. Various lead compounds such as lead monoxide (PbO), red lead (Pb_3O_4), lead sulfate, chromate, and titanate serve as pigments in paints, varnishes, and printing inks. Other applications include lead arsenate in insecticides, lead borate in plastics, and tetraethyl lead as a gasoline additive[3]. Despite the well-documented toxic effects of lead (Pb), occupational lead poisoning continues to be reported across the world. Lead is taken up through food and air. The gastrointestinal absorption rate of ingested lead is approximately 10%, depending on several physiological and environmental factors. Once absorbed, lead is distributed among three primary compartments—blood, soft tissues, and mineralizing tissues (such as bones and teeth). Approximately 95% of the total body burden of lead in adults (and about 70% in children) is stored in the skeletal system. In the blood, lead predominantly binds to erythrocytes, interacting mainly with macromolecules such as proteins rich in sulfhydryl groups.

II. Experimental

Samples treated with Triton X-100, deionized water followed by acetone, then dried and subjected to wet acid digestion . Lead content was determined in the resulting clear solutions using a Model **ECIL-4129 of AAS**.The lead levels were determined by operating at a wavelength of 217 nm, with an integration time of 3 seconds, lamp current of 10 mA, and spectral bandwidth of 1.0 nm. Sample solutions from both hair and nail digests were aspirated directly into the flame, and the Pb concentration was quantified spectrophotometrically on calibrated instrument affected with varying standards prepared from lead stock solution. The instrument was sensitive upto approximately 0.25 µg/mL Pb for 1% absorption.

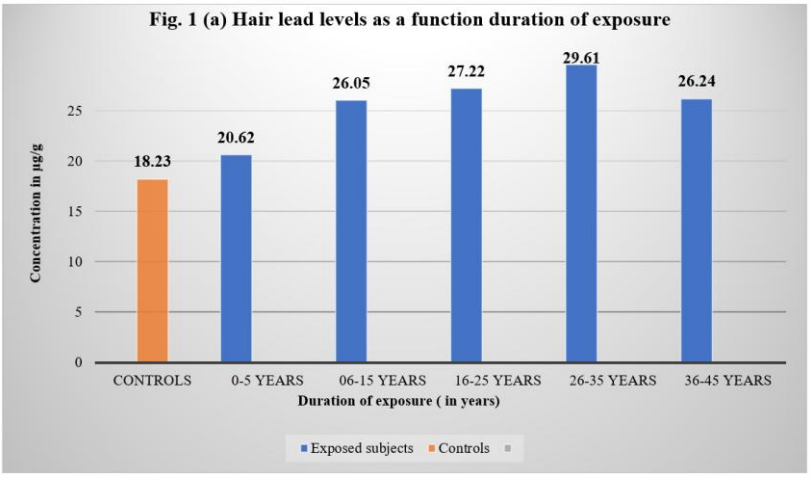
III. Results and Discussion

The concentrations of lead (Pb) in the biopsy materials of subjects from different occupational environments—categorized as exposed and unexposed—were evaluated as a function of various parameters. Table 1 contain mean Pb concentrations with SD in biopsy materials of subjects of varying age groups . No consistent age-related trend was observed in either tissue. Rossi[4] reported a progressive rise in blood lead concentrations with advancing age in adults, and noted that males consistently exhibit more Pb concentrations than females across all adult age groups. Schroeder and Nason[5] analyzed hair samples from individuals aged 1 to 102 years and compared trace metal levels in younger subjects (up to 30 years) with those aged 40–70 years. They found that Pb concentrations were significantly lower in older individuals (8.4 ± 1.20 ppm) than in the younger group (24.5 ± 4.90 ppm). Similarly, Petering et al[6] observed an age-dependent decline in Pb levels in males—from 25 ppm at 2 years to 10 ppm at 85 years—while in females, Pb rose from 4 ppm at age 14 to a peak of 40 ppm at 35 years, before declining to 2 ppm at 84 years. Murata et al[7] reported high vulnerability to increased blood lead concentrations than adults. This heightened sensitivity is partly due to their greater lead intake, as children breathe faster and are more prone to contact with and ingestion of contaminated soil.

Table 2 provides Pb concentrations as a function of occupation . Statistical comparison between hair and nail Pb concentrations revealed generally higher levels in nails, consistent with prior findings[8-9]. Overall, exposed workers showed markedly higher Pb accumulation than unexposed controls. The differences were significant among metal finishing workshops in nails & in other workers in hair samples. Occupations known for Pb exposure. For welders and battery workers similar results are obtained in other studies [10-11].

In [Fig. 1 (a) & 1 (b)] categorizes both exposed and unexposed subjects according to exposure duration 0-5,6-15,16-25,26-35,36-45 years (after excluding outliers). A progressive increase in Pb concentrations with longer exposure was evident. However one or two exception are there Pb levels were significantly higher in exposed subjects than in controls, reflecting a direct relationship between body Pb burden—as measured through hair and nail analyses—and occupational exposure. The main routes of Pb entry into the body include ingestion of contaminated food and water, as well as inhalation of Pb-laden dust and fumes.

In [Fig. 2 (a) & 2 (b)] summarizes Pb levels in relation to smoking habits. Overall, Pb concentrations were significantly higher in smokers compared to non-smokers in hair and only in 31-40 and 51-60 years in nail matrices. Wolfsperger et al reported similar findings, with Pb concentrations of 3.42 ppm (n = 20) in smokers versus 1.47 ppm (n = 59) in non-smokers. Tobacco contains appreciable amounts of Pb, which is efficiently absorbed through pulmonary routes—approximately 30–50%—while gastrointestinal absorption is only about 10%. Friberg et al[12] estimated Pb contents of 3–12 µg per cigarette, and others reported an average of 2.4 µg/g, of which nearly 6% enters mainstream smoke[13]. Household smokers also exhibited higher Pb levels than non-smokers, difference being statistically insignificant, as noted by Schumacher et al Consistent findings of elevated Pb accumulation among smokers have been confirmed by other studies[14, 15].



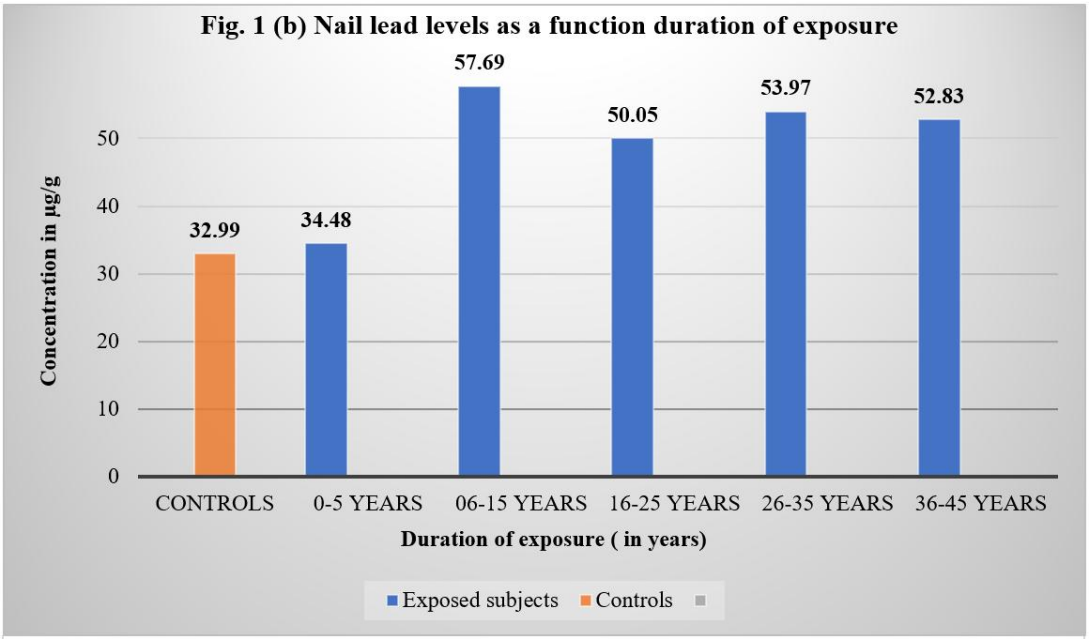


Fig. 1 (b) Nail lead levels as a function duration of exposure
Concentration in µg/g
0
10
20
30
40
50
32.99
34.48
57.69
50.05
53.97
52.83
CONTROLS
0-5 YEARS
06-15 YEARS
16-25 YEARS
26-35 YEARS
36-45 YEARS
Duration of exposure (in years)
Exposed subjects
Controls

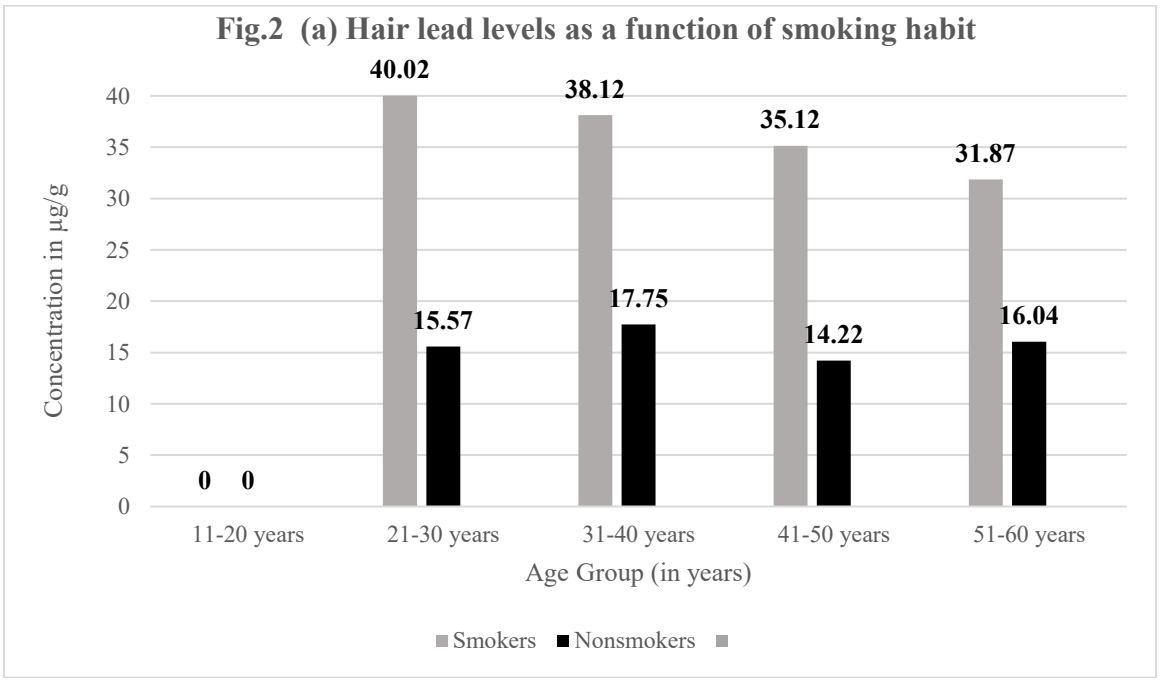


Fig.2 (a) Hair lead levels as a function of smoking habit
Concentration in µg/g
0
5
10
15
20
25
30
35
40
0
0
40.02
15.57
38.12
17.75
35.12
14.22
31.87
16.04
11-20 years
21-30 years
31-40 years
41-50 years
51-60 years
Age Group (in years)
Smokers
Nonsmokers

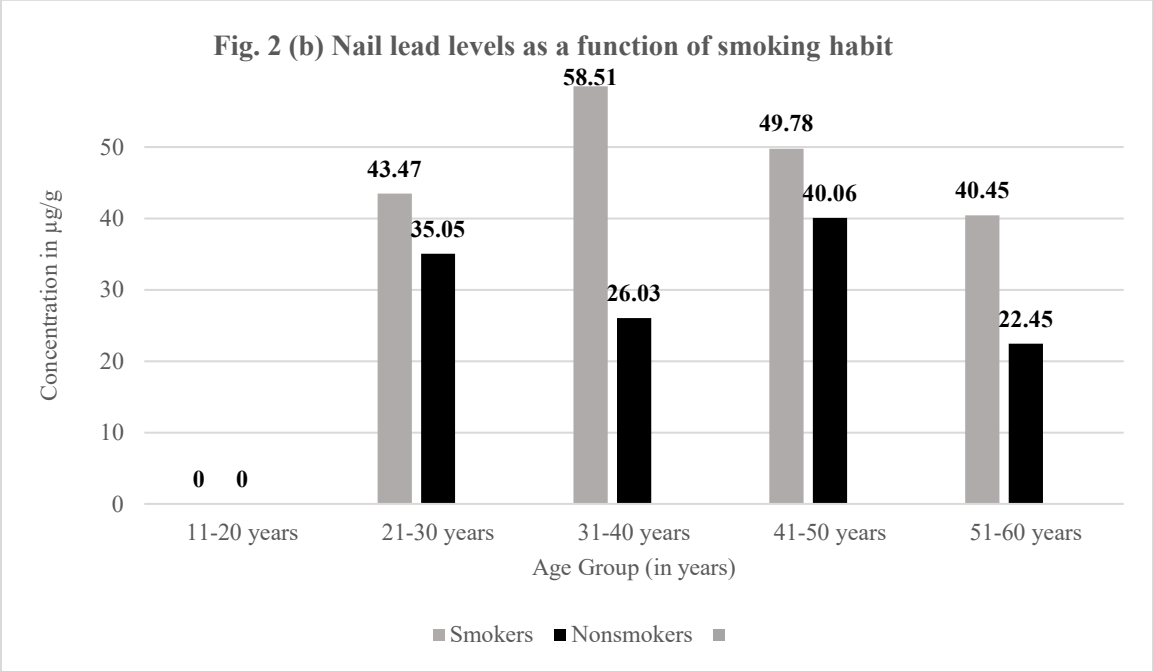


Table 1- Range and mean lead levels (µg/g) in hair and finger nails of subjects of varying age groups

Age in years	No. of samples	Hair		Fingernails	
		Range(µg/g)	Mean± SD(µg/g)	Range (µg/g)	Mean± SD (µg/g)
11-20	47	1.07-74.22	22.40 (21.57)	10.34-123.03	51.16 (33.67)
21-30	77	2.36-55.62	17.87 (12.13)	11.04-123.80	50.44 (32.12)
31-40	71	1.22-79.40	19.66 (19.02)	11.39-122.81	55.36 (35.09)
41-50	79	0.87-66.67	14.92 (14.48)	12.35-124.90	48.97 (33.39)
51-60	66	0.80-173.44	21.74 (26.55)	10.53-125.69	44.61 (30.25)

Table 2- Range and mean lead levels (µg/g) in hair and finger nails of subjects with different occupational exposure.

Subjects	Age in years	No. of samples	Hair		Fingernails	
			Range(µg/g)	Mean± SD(µg/g)	Range (µg/g)	Mean± SD (µg/g)
Controls	11-30	22	1.07-75.21	19.08 (13.27)	10.34-126.01	47.17 (34.03)
Automobile Workshops	11-30	24	1.41.42.7	38.12 (35.85)*	18.29-98.77	55.85 (28.34)
Locomotive Workshops	11-30	23	2.31-54.51	34.12 (25.79)*	10.33-123.80	47.40 (29.25)
Jewelry Manufacturing Units	11-30	26	2.32-56.02	32.13 (27.12)*	10.34-126.01	52.01 (37.91)
Metal Finishing Workshops	11-30	29	3.27-74.22	30.12 (21.23)*	10.33-142.79	70.23 (37.74)*
Control	31-60	41	2.21-46.50	15.92 (14.79)	10.31-124.79	34.50 (36.41)
Automobile Workshops	31-60	43	0.83-65.66	27.52 (17.97)*	10.53-125.69	46.37 (30.05)
Locomotive Workshops	31-60	42	0.83-47.12	24.6 (13.47)*	10.33-126.01	49.03 (34.38)
Jewelry Manufacturing Units	31-60	46	0.80-173.44	24.25 (22.65)*	9.52-124.79	37.57 (28.77)
Metal Finishing Workshops	31-60	44	2.44-71.84	23.99 (19.70)*	10.32-96.26	50.22 (28.82)*

*Values significant at P<0.05 level

Table 3 Range and mean lead levels (µg/g) in hair and finger nails of subjects with health disorders and their respective controls.

Subjects	No. of samples	Hair		Fingernails	
		Range(µg/g)	Mean± SD(µg/g)	Range (µg/g)	Mean± SD (µg/g)
Controls	44	0.82-173.44	16.84 (28.79)	11.37-122.78	36.25 (27.96)
Acidity	39	1.86-59.94	26.55 (18.22)	11.36-122.09	51.44 (37.52)
Diabetes	34	2.35-70.85	24.44 (21.03)	10.34-119.89	49.84 (36.23)
Hypertension	32	3.22-48.13	35.90 (13.02)*	11.41-96.44	58.19 (29.05) *
Hypotension	36	0.87-48.11	42.96 (12.17)*	11.32-125.02	47.23 (32.06)
Mental Stress	43	2.43-74.08	38.40 (16.19)*	10.53-124.02	55.27 (37.94) *
Reproductive Disorder	23	2.23-47.12	42.72 (11.03)*	12.49-95.26	44.32 (31.13)
Respiratory Problem	46	0.80-52.38	35.12 (11.85)*	11.34-125.69	56.53 (34.55) *

Skin Disease	43	0.87-70.40	23.05 (22.40)	10.93-121.81	49.54 (32.31)

*Values significant at P<0.05 level

Table 3 contain the mean Pb concentrations in the tissue samples of subjects with various health disorders, compared to controls . Statistical comparison using the Student's *t*-test ($p < 0.05$) revealed significantly elevated Pb levels in subjects experiencing hypertension, mental stress & respiratory problems. However, the absence of significance in other disorders does not imply a lack of metabolic effects, as sample preparation factors—such as washing procedures, cosmetic use, or external contamination—may introduce minor variations. Lead exposure is related to hypertension through its interference with neural regulation[16] and with haematological and biochemical changes, including elevated coproporphyrin and reduced haemoglobin levels, potentially leading to heart disease[17-19]. Furthermore, neurological impairments, including mental retardation in children due to Pb exposure has been reported by Shrestha and Carrera[20] and by Kostial and Momcilovic[21], who related cognitive deficits to Pb in drinking water. Pb exerts marked effects on the nervous system; studies from the University of Maryland revealed a strong negative correlation between children's hair Pb levels and IQ (WISC-R), along with electrophysiological evidence of altered brain function[22-23].

Okoro et al[24] in Ilorin, Kwara State, Nigeria took a study to assess the fingernail metal levels of young school students and selected adults, with the aim of evaluating their extent of exposure to these metals. Amanah et al[25] analyzed hair samples to assess occupation-related exposure to lead and copper, and their findings indicated insignificant exposure levels. Promila et al[26] carried a research on occupational exposure to various metals to find that lead (Pb) exposure constitutes a significant occupational risk for autoworkers. A correlation ($p < 0.05$) existed between lead (Pb) concentrations in the two biopsy materials of occupationally exposed subjects relative to controls. In addition, cadmium levels in hair and nails showed significant correlations in both exposed and unexposed groups[27].According to Petit et al[28] biomarkers of lead (Pb), cadmium (Cd), and arsenic (As) exhibited weak to strong statistically significant correlations, suggesting a shared environmental source for lead exposure.

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