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ORIGINAL RESEARCH ARTICLE

Evaluation of Plasma Lead and Oxidative Stress Markers in Petroleum Workers

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Abstract

Background Lead toxicity is associated with increased production of free radicals and oxidative stress. This study assesses plasma lead levels and oxidative stress markers, including superoxide dismutase, glutathione peroxidase, malondialdehyde, and catalase, among petroleum station workers.

Methods A case-control study was conducted in Khartoum State between September 2021 and June 2022. Plasma lead levels were measured using atomic absorption spectrophotometry, while oxidative stress markers (SOD, GSH, MDA, and CAT) were analyzed via spectrophotometric methods.

Results Plasma lead levels were significantly higher in cases than in controls ($p = 0.000$). Catalase activity was significantly lower in cases ($p = 0.01$), whereas GSH levels were higher ($p = 0.000$). Plasma lead levels showed a positive correlation with worker age ($r = 0.83$, $p = 0.03$). SOD activity correlated with both age and occupational duration ($r = 0.41$, $p = 0.00$; $r = 0.30$, $p = 0.03$), while GSH correlated with occupational duration ($r = 0.83$, $p = 0.02$).

Conclusion Lead exposure significantly impaired the function of antioxidant enzymes (GSH-Px and CAT) and was related to age and job duration. The findings support the imperative of occupational health intervention aimed at preventing lead-induced oxidative stress in petroleum workers. The results emphasize the importance of implementing targeted public and occupational health policies, including regular biomonitoring, stricter exposure controls, and antioxidant supplementation strategies, to prevent long-term adverse health consequences in exposed individuals.

Keywords Antioxidant enzymes, Lead poisoning, Occupational health, Oxidative stress, Petroleum workers

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1 Introduction

Lead toxicity represents a significant environmental health issue, and its impact on the human body is catastrophic. Virtually every function within the human body is influenced by this condition.[1] Although previously used more widely in fuel additives, batteries, and paints due to its density and resistant properties, lead persists in the environment and bioaccumulates in exposed populations.[2] Petroleum station workers are likely to be significantly exposed to chronic lead levels in fumes containing lead compounds from leaded fuel, which accumulate over time to create blood-borne lead levels leading to multi-system toxicity.[3,4]

Lead's toxic impact occurs through several pathways, as it inhibits heme biosynthesis, disrupts calcium levels, and impairs neurotransmitter release and related processes, all of which are consistent contributors to neurotoxic and hematological effects.[5,6] Epidemiological studies have consistently shown associations of lead exposure with cardiovascular disease, renal disease, and reproductive health disease.[7,8] A significant mechanism underlying these effects is the generation of oxidative stress, defined as the excess production of reactive oxygen species (ROS) and/or a decrease in antioxidant defenses.[9,10]

In individuals who have been exposed to lead, excess ROS generation results in oxidation of cellular structures such as lipids, proteins, and DNA.[11,12] Cellular oxidative damage and dysfunction drive pathophysiological cascades that could evolve into chronic conditions including neurotoxic and renal disease.[13,14] Although biomarkers of oxidative stress provide valuable insight into these processes, there is limited knowledge about specific oxidative stress patterns in petroleum sector workers.[14]

This study aims to evaluate plasma lead levels and oxidative stress markers, including superoxide dismutase (SOD), glutathione peroxidase (GSH), catalase (CAT), and malondialdehyde (MDA), among petroleum station workers in Khartoum state, while examining correlations with occupational exposure duration and age. The findings will help assess health risks in this vulnerable population and inform preventive occupational health strategies.

2 Methods

Study population

An Analytical case-control community-based study was conducted at various petroleum stations in Khartoum State from June to September 2022. A total of 100 subjects were enrolled: 50 petroleum station workers as the case group and 50 non-petroleum station workers as the control group.

Inclusion and exclusion criteria

Petroleum station workers aged 18 to 70 were included. Workers with malignancy, chronic diseases, renal diseases, smokers, and those with liver disease were excluded.

Data Collection and Blood Sampling

A structured questionnaire was designed to collect medical and personal information, including age, BMI, and the duration of work. Samples were collected using a sterile disposable plastic syringe after cleaning the vein puncture area with 70 % ethanol. A volume of 5 mL whole blood was collected in a syringe using heparin as an anticoagulant,then centrifuged at 1000-2000 xg for 5 minutes. All plasma samples were immediately stored in a refrigerator at 2–8°C to preserve sample integrity until analysis. The plasma lead was measured using automatic absorption spectrophotometers, while the plasma oxidative stress markers were estimated using spectrophotometric methods.

Ethical Considerations

Before conducting the study, the proposal was approved by the Ethical Committee of National University, and the lab at which the study was done. Informed consent was obtained from all participants in the study.

Data analysis

Results are presented as mean ± standard deviation (SD) and percentages (%). A p-value of ≤ 0.05 was considered statistically significant. The results were analyzed using Statistical Package for Social Sciences (SPSS), version 25. Group comparisons between petroleum workers and controls were conducted using the independent samples t-test for normally distributed data. The Pearson correlation coefficient was used to assess the relationship between plasma lead levels and oxidative stress markers, as well as age, BMI, and duration of exposure. A p-value ≤ 0.05 was considered statistically significant.

3 Results

The age of the case group ranged from 18 to 70 years, with a mean of 34.7 ± 13.3 years, while the age of the control group ranged from 17 to 70 years, with a mean of 31.2 ± 8.6 years. The duration of exposure among petroleum fuel workers ranged from 1.6 to 34 years, with a mean of 8.8 ± 10.1 years. The BMI of the case group ranged from 15.3 to 25.6, with a mean of 21.1 ± 1.5, while the BMI of the control group ranged from 17.3 to 30.5, with a mean of 24.1 ± 2.5 (Table 1).

The common symptoms among petroleum fuel workers were headache (2.4%), kidney pain (4%), and shortness of breath, fever, and allergy (2%), with no symptoms reported in 66% (Figure 1).

Table 1 Descriptive statistics of the study population

Variables	N	Minimum	Maximum	Mean ± SD
Age (case)	50	18.0	70.0	34.7 ± 13.3
Duration of exposure/years	50	1.6	34.0	8.8 ± 10.1
Age (control)	50	17.0	70.0	31.2 ± 8.6
BMI (case)	50	15.3	25.6	21.1 ± 1.5
BMI (control)	50	17.3	30.5	24.1 ± 2.5

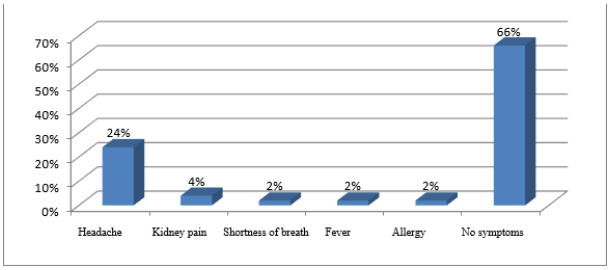

Figure 1 Distribution of symptoms among the case group

The (mean ± SD) of plasma lead, superoxide dismutase, glutathione peroxidase, malondialdehyde, and catalase among petroleum fuel workers, respectively, were (1.6 ± 0.7, 11.9 ± 0.9, 743.9 ± 76.1, 2.0 ± 0.3, 8.6 ± 1.2). While the (mean ± SD) of plasma lead, superoxide dismutase, glutathione peroxidase, malondialdehyde, and catalase among the control group, respectively, were (0.2 ± 0.1, 12.1 ± 1.1, 313.4 ± 52.5, 1.8 ± 0.4, 15.7 ± 2.8). The plasma lead was significantly higher in the case than in the control, with p = 0.000. Plasma catalase was considerably lower in the case group than in the control, with a p = 0.01, while plasma SOD was insignificantly lower in the case group than in the control. Plasma GSH was significantly higher in the case than in the control, with a p = 0.000. Plasma MDA was insignificantly higher in the case than in the control (Table 2).

Table 2 Mean ± SD of plasma lead and oxidative stress markers among study groups

Parameters	Case N = 50	Control N = 50	P - value
Lead	1.6 ± 0.7	0.2±0.1	0.00
SOD	11.9 ± 0.9	12.1 ± 1.1	0.87
GSH	743.9 ± 76.1	313.4 ± 52.5	0.00
MDA	2.0 ± 0.3	1.8 ± 0.4	0.91
CAT	8.6 ± 1.2	15.7 ± 2.8	0.01

Plasma lead was positively correlated with the age of petroleum fuel workers (r = 0.83, p = 0.03) and not correlated with BMI and duration of working as a petroleum fuel worker, respectively (r = -0.06, p = 0.67, r = -0.02, p = 0.88). Plasma SOD was positively correlated with age and duration of working of petroleum fuel workers, respectively (r =0.41, p = 0.00, r = 0.30, p = 0.03), while plasma SOD was uncorrelated with BMI (r = -0.14, p = 0.31). Plasma GSH levels exhibited a strong positive correlation with the duration of occupational exposure among petroleum fuel workers (r = 0.83, p = 0.02). However, no significant correlations were found between plasma GSH levels and either age (r = –0.21, p = 0.61) or BMI (r = –0.44, p = 0.72) in this population. Plasma MDA levels showed no significant correlations with age (r = –0.05, p = 0.81), BMI (r = –0.32, p = 0.37), or duration of work (r = –0.11, p = 0.63) among petroleum fuel workers. Similarly, plasma catalase activity was not significantly correlated with age (r = 0.03, p = 0.78), BMI (r = –0.41, p = 0.56), or duration of work (r = 0.11, p = 0.47) in this group (Table 3).

Table 3 Correlation between lead and oxidative stress with age, BMI, and the duration of work among petroleum fuel workers

	Variables	r	P - value
Lead	Age	0.83	**0.03**
	BMI	-0.06	0.67
	Duration of working	-0.02	0.88
	Variables	r	P - value
SOD	Age	0.41	**0.00**
	BMI	-0.14	0.31
	Duration of working	0.30	**0.03**
	Variables	r	P - value
GSH	Age	-0.21	0.61
	BMI	-0.44	0.72
	Duration of working	0.83	**0.02**
	Variables	r	P - value
MDA	Age	-0.05	0.81
	BMI	-0.32	0.37
	Duration of working	-0.11	0.63
	Variables	r	P - value
CAT	Age	-0.03	0.78
	BMI	-0.41	0.56
	Duration of working	0.11	0.47

The case group was older and had a lower BMI compared to the controls. The mean occupational exposure duration among petroleum workers was approximately 9 years. The symptoms reported were not severe in nature, and the majority (66%) of them were asymptomatic.

Plasma lead levels were considerably greater in petroleum workers compared to controls. Similarly, there were remarkable alterations in oxidative stress markers: catalase activity was notably decreased, while GSH levels were significantly elevated in the exposed group. In contrast, SOD and MDA levels were not significantly different between groups.

Correlation analysis revealed that plasma lead levels were positively associated with age but were not significantly correlated with BMI or work duration. SOD activity was associated with age and duration of occupation, while GSH level was associated with duration of exposure. No significant correlations were observed for MDA and CAT with any of the demographic factors.

4 Discussion

This study highlights significant differences in plasma lead levels and oxidative stress markers between petroleum fuel workers and a control group, emphasizing the impact of occupational exposure to petroleum fumes.

1. Plasma Lead Levels

The current research reconfirmed significantly elevated plasma lead levels in petroleum station attendants in Japan compared with controls, consistent with previous reports that occupational exposure leads to systemic bioaccumulation of lead via inhalation of fuel vapors or skin contact.[3,4] The excellent positive correlation between plasma lead and age suggests cumulative exposure over time, emphasizing the chronicity of occupational lead ingestion. However, the absence of correlation with duration of employment could be due to the influence of other factors such as job position, environmental conditions, or protection procedures.

2. Oxidative Stress Markers

Long-term exposure to lead has been found to induce oxidative stress by generating reactive oxygen species (ROS) and impairing the antioxidant defense system.[9,10] In this study, petroleum workers showed significantly decreased catalase activity, indicating an exhausted antioxidant defense system. Catalase plays a role in detoxifying hydrogen peroxide, and its inhibition can reflect oxidative enzyme inactivation due to chronic ROS exposure.[11,13] The identical reductions in catalase activity have been observed in other working populations with lead exposure.[14]

Unexpectedly, the concentrations of GSH were exceedingly high in petroleum workers. This may be a manifestation of compensatory upregulation against oxidative stress. The upregulation of GSH synthesis has been reported in cells and tissues subjected to lead as a protective measure, although chronic stress can eventually exhaust antioxidant defenses if not matched by cellular recovery.[12,14]

SOD activity was slightly reduced and was not significant, but its positive correlation with both occupational duration and age suggests adaptive enzyme regulation as a response to long-term exposure. In contrast, MDA levels—a marker for lipid peroxidation—were not different, suggesting either mild peroxidative damage or antioxidant compensation in the early or moderate phases of exposure.

3. Correlation Analysis

The correlation between lead and age, but not with BMI or length of employment, suggests that age is a determinant of cumulative exposure. Conversely, SOD and GSH were both positively correlated with exposure duration, supporting the notion that the body's antioxidant defense responds dynamically to chronic stress. These findings highlight the intricate relationship between exposure duration, biological age, and oxidative balance.

4. Public and Occupational Health Implications

The altered oxidative stress markers and elevated lead levels in petroleum workers pose a stark occupational hazard that can predispose them to long-term health conditions such as cardiovascular, renal, or neurological disease. The findings underscore the urgent need for evidence-based public health action, including regular biomonitoring programs for the early detection of lead toxicity, policy enactment on the safe working environment and lead-free fuel sources, mandatory use of personal protective equipment (PPE) and ventilation systems in fueling stations, and antioxidant supplementation programs, such as dietary intervention or supplementation, used to neutralize oxidative damage. Future research should consider more comprehensive lifestyle and environmental cofactors and incorporate longitudinal designs to assess progression and health outcomes over time.

Study Limitations

This study has several limitations that could be considered when interpreting the results. The relatively small sample size may limit the generalizability of the findings to a broader population of petroleum station workers. Additionally, the study did not account for potential confounding variables, such as smoking, alcohol consumption, dietary habits, or genetic predispositions, which could influence oxidative stress levels. Future studies with larger sample sizes and more comprehensive assessments of lifestyle factors are needed to validate and expand upon these findings.

5 Conclusion

Lastly, this article highlights the occupational health risks faced by petroleum station employees, as evidenced by elevated plasma lead concentrations and disruptions to oxidative stress markers. These findings underscore the importance of preventive occupational health. Continuous surveillance of biomarkers for oxidative stress, regular surveillance of lead levels, and provision of correct PPE are imperative in the prevention of long-

term effects of lead exposure.

Public health policy should focus on occupational safety education, environmental remediation, and nutritional interventions to enhance antioxidant defense in exposed workers. Genetic susceptibility, lifestyle, and broader, more diverse populations would need to be investigated by future studies to validate these data and gain further mechanistic understanding.

Declarations

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Artificial Intelligence Disclosure
The authors confirm that no artificial intelligence (AI) tools were used in the preparation of this manuscript.

Authors' Contributions
GadAllah Modawe collected the data, and all authors contributed to the study's design, analysis, writing, typing, and article revision.

Availability of Data and Materials
The authors confirm that the data supporting the findings of this study are available within the article and/or its supplementary materials.

Conflict of Interest
The authors declare no conflict of interest.

Consent for Publication
Not applicable.

Ethical Considerations
Before conducting the study, the proposal was approved by the Ethics Committee of the National University under the Code of Ethics NU-REC/06-022/7, and the lab where the study was conducted. All participants provided informed consent prior to inclusion in the study.

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