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RESEARCH ARTICLE

THE EFFECT OF OCCUPATIONAL BENZENE EXPOSURE DURATION ON HEMATOLOGICAL PARAMETERS AMONG FUEL STATION WORKERS IN MUKALLA CITY, YEMEN

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Abstract

Chronic occupational exposure to benzene is a major health hazard that directly affects the hematopoietic system. Therefore, this study aimed to evaluate the effect of benzene exposure duration on physiological blood parameters among fuel station workers in Mukalla city. A cross-sectional study was conducted from January to May 2023, involving 46 male workers at fuel stations, and 23 healthy individuals as a control group. The participant's ages ranged between 20-70 years. Workers were divided into two groups based on exposure duration: (1-4 years) and (5-8 years). A complete blood count (CBC) analysis was performed using a Sysmex XP-300 analyzer, and data were statistically analyzed using SPSS version 24.0. The results revealed a significant decrease ($P < 0.05$) in red blood cell (RBC) count, hemoglobin concentration (Hb), hematocrit (HCT), and mean corpuscular hemoglobin concentration (MCHC), while white blood cell (WBC) count and the percentage of neutrophils (NEUT) and monocytes (MON) were significantly increased ($P < 0.05$) compared to the control group. Statistical analysis also revealed a cumulative toxic effect of benzene; workers with more than 5 years of exposure exhibited a more significant decrease in Hb value, RBC count, HCT percentage, MCHC and lymphocytes, while more significant increase in WBC count, percentage of NEUT and MON compared to those with shorter durations. The study concluded that exposure duration is a crucial factor in predicting the occurrence of anemia and immune disorders, necessitating periodic hematological monitoring and the use of personal protective equipment to mitigate occupational health risks for fuel station workers.

Keywords: Benzene; Fuel stations; Hematological parameters; Hematotoxicity; Mukalla city; Occupational exposure.

1. Introduction

Occupational pollution by toxic chemicals is one of the most prominent challenges facing public health and occupational medicine in the modern era. Benzene—a volatile aromatic hydrocarbon widely used as a basic component in motor fuels—represents one of the most dangerous environmental and occupational pollutants [1]. Due to its physical properties, benzene evaporates easily at normal temperatures, making the inhalation of its vapors and absorption through the skin among the most common exposure routes for fuel station workers [2]. Epidemiological studies indicate that chronic exposure to benzene, even at low levels, leads to severe disruptions in the cellular components of the blood, as benzene, through its metabolites, suppresses the bone marrow and causes genetic mutations that may develop into cancers [3-5]. In addition to immune system dysfunction, which explains the sharp decline in specific immunity among fuel station workers [6].

Several studies have indicated that fuel station workers suffer from a notable decrease in red blood cell (RBC) count and hemoglobin (Hb) concentration, alongside disturbances in white blood cell (WBC) count as an immuno-inflammatory response to chemical toxicity [7].

Regionally, recent research in similar Arab environments confirmed that the lack of personal protective equipment use doubles exposure risk, leading to early signs of hematotoxicity among workers [8]. The toxic effects of benzene are not limited to the physiological aspect but extend to oxidative stress targeting vital organs like the liver and kidneys [9], [10].

Exposure duration is a critical variable in determining the extent of health damage; hematotoxicity severity increases cumulatively with more years of work in this field [11]. Recent systematic reviews showed that changes in blood indices can be used as early biomarkers to predict health disorders caused by volatile organic compounds [12]. Classifying workers based on their years of service also contributes to a precise understanding of the threshold at which physiological indicators begin to collapse [13].

Despite the critical importance of this topic, there is a clear scarcity of local studies addressing the occupational health of fuel station workers in Yemen in general and Hadhramout governorate in particular. In light of the lack of strict occupational safety standards implementation in local fuel stations, this study came to bridge this research gap. Accordingly, this study aims to evaluate the effect of occupational benzene exposure duration on physiological hematological parameters among fuel station workers in Mukalla city, to provide a scientific database that contributes to enhancing preventive policies and providing a safe work environment.

2. Materials and Methods

2.1 Study Design and Setting

This analytical cross-sectional study was conducted to evaluate the hematological effects resulting from occupational benzene exposure. Its field framework was implemented in fuel stations within Mukalla city, Hadhramout Governorate, during the period from January to May 2023.

2.2 Study Population and Sampling

The study sample consisted of 69 male participants, aged between 20-70 years, divided into two main groups:

*Workers Group: Included 46 fuel station workers, operating on direct regular shifts. For the purpose of studying the effect of time duration, they were subdivided based on occupational exposure duration into two groups: the first group (1-4 years) and the second group (5-8 years).

* Control Group: Included 23 healthy individuals not occupationally exposed to benzene, matched with the workers in terms of age group and general living conditions to ensure comparison accuracy.

2.3 Inclusion and Exclusion Criteria

* Inclusion Criteria: Field workers in fuel filling who voluntarily agreed to participate in the study.

* Exclusion Criteria: To ensure that hematological changes are primarily caused by benzene exposure, any participant (whether from the workers or the control group) suffering from chronic diseases such as kidney or liver diseases, hereditary blood diseases, a recent history of blood transfusion or surgeries, taking medications affecting the bone marrow, or having a history of smoking, was excluded.

2.4 Ethical Approval

Official permission and approval to conduct the research were obtained after approving the research plan, by applying for permission from the Faculty of Science - Hadhramout University, as well as obtaining informed consent from the study targets and the station owners where they work. Total confidentiality of medical and personal data and its use solely for scientific research purposes were guaranteed.

2.5 Methods

2.5.1 Data Collection Tool:

Field visits to the study area were conducted to obtain study-related information through a prepared questionnaire. The questionnaire included the exposed worker's name, age, years of work at fuel stations, presence and type of chronic diseases (if any), and smoking status.

2.5.2 Blood Sampling and Laboratory Analysis:

About 3 ml of venous blood samples were drawn from all participants under standard sterile conditions. The samples were immediately placed in tubes containing anticoagulant (EDTA) to prevent blood clotting, and kept refrigerated until transported to the laboratory. A Complete Blood Count (CBC) analysis was performed within a few hours of sample collection to ensure cell viability, using a Sysmex XP-300 Automated Hematology Analyzer.

2.6 Statistical Analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS version 24.0). Descriptive statistics (Mean ± SD) were used to describe variables. To test for significant differences between groups, the Independent Sample (t)-test was used to compare total workers and the control group, and One-Way ANOVA was used to compare different exposure duration categories (1-4 years, 5-8 years) and the control group. Results were considered statistically significant at a probability level of ($P \leq 0.05$).

3. Results

3.1 Distribution of Benzene-Exposed Samples According to Exposure Duration

The study included 46 workers at fuel stations, divided according to years of exposure into two groups. The group exposed to benzene for (1-4) years represented the largest percentage at 65.22%, and the group exposed for (5-8) years accounted for 34.78%.

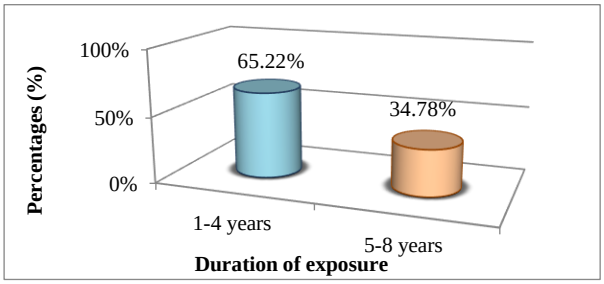

Fig. (1): Distribution of exposed to benzene according to exposure duration

3.2 Hematological Parameters in Worker group and Control Group

The statistical analysis results in Table (1) indicated significant differences in the blood profile between the benzene-exposed group and the control group. These differences were represented by a significant decrease in RBC count, Hb concentration, HCT percentage, and MCHC in the benzene-exposed group compared to the control group. Concurrently, total WBC count and the percentage of the differential count for neutrophils and monocytes increased significantly in the exposed group compared to the control group. Conversely, MCV, MCH, platelet count, and the differential percentages of lymphocytes, eosinophils, and basophils did not show any statistically significant.

Table (1): Hematological parameters between two study groups

Parameters	Groups (Mean ± S.D)		*p*-Value
	Control Group (n= 23)	Workers Group (n= 46)	
RBC (10^6/ µl)	5.39 ± 0.48	4.86 ± 0.68	0.002
HB (g/dl)	15.32 ± 0.92	14.19 ± 1.16	0.001
HCT %	42.2 ± 4.02	39.84 ± 4.05	0.025
MCV (FL)	76.46 ± 4.83	78.07 ± 5.75	0.253
MCH (pg)	27.64 ± 2.51	27.49 ± 2.49	0.820
MCHC (g/dL)	36.13 ± 1.46	34.83 ± 1.54	0.001
PLT (10^3/µl)	255.91 ± 35.71	263.65 ± 41.53	0.448
WBC (10^3/ µl)	4.95 ± 1.61	6.98 ± 2.05	0.001
NEUT %	45.62 ± 6.73	49.39 ± 9.15	0.036
LYM %	40.68 ± 7.81	38.91 ± 7.88	0.380
MON%	8.34 ± 1.48	9.68 ± 2.14	0.009
EOS%	3.16 ± 2.38	4.13 ± 2.36	0.113
BAS%	0.64 ± 0.27	0.83 ± 0.42	0.063

3.3 Cumulative Effect of Exposure Duration on Hematological Parameters

The statistical analysis results in Table (2) demonstrated an exacerbation in hematological disorders directly proportional to the increase in years of work at fuel stations. RBC count, Hb concentration, and MCHC decreased significantly in both benzene-exposed groups compared to the control group, and this decrease was more pronounced in the longer-exposed group (5-8 years) than in the shorter-exposed group (1-4 years). While total WBC count increased significantly in both exposed groups compared to the control group, this increase was more pronounced in the longer-exposed group. The long-exposure group (5-8 years) uniquely recorded significant changes that did not appear in the short-exposure group, including a significant decrease in HCT percentage and lymphocyte differential count, and a significant increase in neutrophil and monocyte differential counts compared to the control group. On the other hand, MCV, MCH, platelet count, and eosinophil and basophil differential counts remained stable without registering any significant differences attributed to varying exposure durations.

Table (2): Effect of duration of benzene exposure on hematological parameters

Parameters	Control Group (n= 23)	Groups (Mean ± S.D)	
		Workers Group (n= 46)	
		1-4 Years (n=30) 4	5-8Years (n=16)
RBC (10^6/ µl)	5.39 ± 0.48	4.88 ± 0.70 **	4.84 ± 0.97**
HB (g/dl)	15.32 ± 0.92	14.31 ± 0.86***	13.97 ± 0.68***
HCT %	42.2 ± 4.02	40.46 ± 3.14	38.7 ± 5.3*
MCV (FL)	76.46 ± 4.83	78.22 ± 5.63	77.78 ± 6.15
MCH (pg)	27.64 ± 2.51	27.64 ± 2.35	27.21 ± 2.79
MCHC (g/dL)	36.13 ± 1.46	35.13 ± 0.86**	34.26 ± 2.27**
PLT (10^3/µl)	255.91 ± 35.71	262.43 ± 37.88	265.94 ± 48.91
WBC (10^3/ µl)	4.95 ± 1.61	6.24 ± 1.57**	8.36 ± 2.17***
NEUT %	45.62 ± 6.73	46.69 ± 9.36	51.73 ± 7.3*
LYM %	40.68 ± 7.81	40.71 ± 8.17	35.51 ± 6.21*
MON%	8.34 ± 1.48	9.22 ± 1.36*	10.16 ± 1.17**
EOS%	3.16 ± 2.38	3.54 ± 2.72	3.38 ± 1.24
BAS%	0.64 ± 0.27	0.79 ± 0.45	0.76 ± 0.37

* = Significant differences between the control and exposure groups at a probability level of P<0.05

** = Significant differences between the control and exposure groups at a probability level of P<0.01

*** = Significant differences between the control and exposure groups at a probability level of P<0.001

4. Discussion

Fuel station workers are regularly exposed to various toxic components of benzene, causing abnormal changes in the function of many vital organs. As a result of metabolic processes, these toxins settle in the liver, thereby increasing peroxidized lipid levels, leading to extensive damage to the liver, kidneys, heart, and bone marrow [14]. The risk of this exposure increases in hot work environments like Mukalla city; studies indicate that elevated ambient temperatures increase the volatilization rates of Volatile Organic Compounds (VOCs), including benzene, doubling the daily inhaled dose and accelerating its entry into the bloodstream [10]. Although the mean daily temperature in Mukalla city during the data collection period was obtained from local meteorological records, specific temperature measurements at each fuel station were not recorded directly by the researchers. This study aimed to identify and evaluate the effect of benzene exposure duration on physiological blood indices among fuel station workers in Mukalla city and compare them with a group of unexposed individuals.

Statistical analysis results showed significant differences between the benzene-exposed group and the control group, manifested by a significant decrease in RBC count, Hb concentration, and HCT percentage. This decrease was more pronounced in the longer-exposed group (5-8 years) compared to the shorter-exposed group (1-4 years). This finding aligns with the results of [7] conducted in Ethiopia. The reason is attributed to various toxic effects arising from benzene and its components, leading to free radical formation, which in turn alters the RBC membrane and suppresses bone marrow function, causing aplastic anemia [1], [15]. However, the current study's findings disagreed with [16] in Iraq, which recorded a significant increase in these values, attributing it to the effect of carbon monoxide and hypoxia, which stimulates erythropoietin hormone to produce more RBCs [17].

The results also revealed a significant decrease in MCHC among those exposed to benzene, being more severe in those with longer exposure (5-8 years). These findings agree with [18] in Nigeria, [9] in Iraq, and [19] in Libya. This is attributed to benzene's effect on cell elasticity and permeability, and cell membrane destruction by free radicals [20]. Conversely, this finding differed from [5] in Sudan, which recorded a significant increase; this contradiction might be due to variations in sample size, nutritional status, and exposure duration. MCV and MCH values were not affected in our study, agreeing with [21] in Indonesia, and differing from [22] in China, which showed a decrease, and [23], which recorded an increase.

Regarding the immune response, the statistical analysis recorded a significant increase in total WBC count among benzene-exposed individuals, peaking in the longer-exposed group. This agrees with [24] in Palestine, and [19] in Libya. This increase is attributed to the immunosuppressive effect of toxic benzene products, stimulating the body as a defensive reaction to increase WBC production [25]. This finding contradicted studies that recorded a decrease [26] or no effect [5]. The rise in WBCs is a vital indicator of the body entering a state of systemic chronic inflammation as a direct reaction to continuous oxidative stress. Recent studies confirm that prolonged exposure to fuels keeps the bone marrow in a constant state of alert, which may explain the subsequent cellular exhaustion in advanced stages [8].

At the differential count level, our study recorded no significant overall differences in neutrophils compared to the control group, agreeing with [27] in Iraq, and disagreeing with [28] in Egypt, which recorded a decrease due to the failure of macrophage migration in a way that could affect workers' immune processes, rendering them weak and more susceptible to various infections. Lymphocytes also showed no overall change, agreeing with [29] in Iran, but decreased significantly in the longer-exposed group (5-8 years) compared to the control, differing from [30] in Nigeria. This variation based on working years is a key outcome of our study; it proves the immune depletion theory. In the first years, the body successfully maintains lymphocyte levels, but upon crossing the 5-year barrier of cumulative benzene toxicity, actual bone marrow suppression begins, exposing older workers to a higher risk of opportunistic infections and tumors [11]. The study also showed a significant increase in monocytes, especially among those with long exposure, agreeing with [31] in Iraq and differing from [28] in Egypt. This increase is attributed to the immune system's response to tissue damage caused by benzene's toxic effects [25]. Eosinophils and basophils were not significantly affected, agreeing with [28].

Finally, our study's findings is consistent with [32] regarding the unaffected platelet count by benzene exposure, explained by thrombopoietin not being affected by benzene components, while it disagreed with results showing a significant increase in platelets [16], [22].

5. Study Limitations

Despite the importance of the findings of this study, some limitations must be considered. The study was limited to measuring phenotypic hematological parameters (CBC) without the ability to measure actual benzene vapor concentration in the work environment (Air monitoring) or measure urinary benzene metabolites (like muconic acid), due to limited technical and resource capabilities. Furthermore, while the sample size was statistically sufficient to demonstrate differences, it warrants

larger-scale future studies that include other governorates in Yemen.

6. Conclusions

This study concluded that occupational exposure to benzene has a significant toxic effect on the hematopoietic system. The results conclusively demonstrated a cumulative effect over time; exceeding 5-year work duration represents a critical turning point where hematological disorders exacerbate. This is clearly manifested in bone marrow activity suppression (represented by a significant and sharp decrease in RBCs and Hb), and the stimulation of a chronic inflammatory response state (represented by an increase in WBCs and the differential count of neutrophils and monocytes). Therefore, changes in hematological parameters serve as an early biomarker of benzene toxicity before it progresses to serious hematological diseases.

7. Recommendations

The study recommends obligating fuel station owners, in coordination with the Ministry of Health office, to conduct comprehensive periodic blood tests (CBC) for workers at least every six months for early detection of any physiological disturbances. It also recommends the strict enforcement of occupational safety standards by compelling workers to wear carbon-filtered masks and protective gloves to reduce vapor inhalation and dermal absorption. Furthermore, implementing a flexible shift system to reduce continuous exposure hours to vapors within a single day, especially during midday hours when temperatures rise in Mukalla city and the benzene evaporation rate increases.

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مقالة بحثية

تأثير مدة التعرض المهني للبنزين على المعايير الدموية لدى عمال محطات الوقود في مدينة المكلا، اليمن

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المُلخّص

يُعدّ التعرّض المهني المزمن للبنزين خطرًا صحيًا جسيمًا يؤثر بشكل مباشر على الجهاز المكون للدم. لذلك، هدفت هذه الدراسة إلى تقييم تأثير مدة التعرض للبنزين على مؤشرات الدم الفسيولوجية لدى عمال محطات الوقود في مدينة المكلا. أُجريت دراسة مقطعية في الفترة من (يناير إلى مايو 2023م)، شملت 46 عاملًا من الذكور العاملين في محطات تعبئة الوقود في مدينة المكلا و23 شخصًا سليمًا كمجموعة ضابطة. تراوحت أعمار المشاركين بين (20 -70) عامًا. قُسّم العمال إلى مجموعتين بناءً على مدة التعرّض للبنزين: (1-4 سنوات) و(5-8 سنوات). أُجري تحليل تعداد الدم الكامل باستخدام جهاز تحليل Sysmex xp-300, وحُلّلت البيانات إحصائيًا ببرنامج SPSS الإصدار 24.0. أظهرت النتائج انخفاضًا معنويًا ($P < 0.05$) في عدد خلايا الدم الحمراء (RBCs)، تركيز الهيموجلوبين (Hb)، ونسبة الهيماتوكريت (HCT)، ومعدل تركيز هيموجلوبين الكرية (MCHC)، في حين ارتفعت معنويًا ($P < 0.05$) كل من عدد خلايا الدم البيضاء (WBCs) والنسبة المئوية لخلايا الدم البيضاء المتعادلة ووحيدة النواة مقارنةً بمجموعة السيطرة. كما كشف التحليل الإحصائي عن تأثير تراكمي سام للبنزين؛ إذ أظهر العمال الذين تجاوزت مدة خدمتهم 5 سنوات انخفاضًا معنويًا أكثر وضوحًا في عدد خلايا الدم الحمراء ونسبة الهيماتوكريت ومتوسط تركيز الهيموجلوبين الكرية ونسبة الخلايا اللمفاوية، وارتفاعا معنويًا أكثر وضوحًا في عدد خلايا الدم البيضاء ونسبة الخلايا المتعادلة ووحيدة النواة مقارنة بالفئة الأقل تعرضًا. خلُصت الدراسة إلى أن مدة التعرض تُعد عاملًا حاسمًا في التنبؤ بحدوث فقر الدم والاضطرابات المناعية، مما يستوجب إجراء فحوصات دم دورية واستخدام وسائل الحماية الشخصية للحد من المخاطر الصحية المهنية للعاملين في محطات الوقود.

الكلمات المفتاحية: البنزين؛ التعرض المهني؛ السمية الدموية؛ المعايير الدموية؛ محطات الوقود؛ مدينة المكلا.

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