British Journal of Multidisciplinary and Advanced Studies:
Earth Sciences 5 (3),1-23, 2024
Print ISSN: 2517-276X
Online ISSN: 2517-2778
Website: https://bjmas.org/index.php/bjmas/index
Published by European Centre for Research Training and Development UK

Effect of Benzene Exposure on Ferritin and Complete Blood Count in OiLibya420 Gas Station Workers

Abdelmetalab Tarhuni1*, Aisha Hassan[1], Aya Mohammed[1], Aya H Mohammed[1], Nour Alhuda Salem[1], Omima bdullah[1], Huda Mohamed[1], Ali Ateia Elambsout[2], Fatma El Fargani[3], Nagwa Mohamed[3]

[1]Department of Environment, Faculty of Public Health, University of Benghazi, Benghazi, Libya.
[2]Department of Nutrition, Faculty of Public Health, University of Benghazi, Benghazi, Libya.
[3]Department of physiology, faculty of medicine, university of Benghazi, Benghazi, Libya.
*Address for correspondence: Dr. Abdelmetalab Tarhuni, Department of Environment, Faculty of public health, University of Benghazi, Benghazi, Libya. Email address: Abdelmetalab.tarhuni@uob.edu.ly

doi: https://doi.org/10.37745/bjmas.2022.0489 Published May 09, 2024

Citation: Tarhuni A., Hassan A., Mohammed A., Mohammed A.H., Salem N.A., Bdullah O.,Mohamed H., Elambsout A.A., El Fargani F., Mohamed N. (2024) Effect of Benzene Exposure on Ferritin and Complete Blood Count in OiLibya420 Gas Station Workers, *British Journal of Multidisciplinary and Advanced Studies*:Earth Sciences 5 (3),1-23

ABSTRACT: *Benzene is a colorless liquid that easily evaporates in the air and can lead to negative impacts on the workers' health. Also, it can cause cancer. This study aimed to evaluate the effect of benzene on the ferritin level and blood of workers in petrol station. This study has a cross sectional design. It includes 32 participants out of which 16 are exposed workers and 16 non exposed ones. The data was collected by using a questionnaire about socio-demographic characteristics and symptoms of benzene exposure. Also, Blood samples were taken to test ferritin and complete blood counts and analyzed by using Statistical Package for Social Sciences. The results of the study revealed that exposure to benzene in some workers leads to decreasing serum ferritin, MCV, MXD and MCH, and increased WBC, RBC, and HCT. There was a statistical difference in the WBC, RBC, MCV, MCH, LYM, and MXD between the exposed and non-exposed groups. There was a positive relationship between years of experience and effects of benzene on WBC, and a clear correlation between the exposed workers' age, HGB and ferritin levels.*

Benzene has negative impacts on the health of workers, which dictates the necessity of worker wearing personal protective equipment in the workplace.

KEYWORDS: benzene, complete blood count CBC, exposure, ferritin, gas station, workers.

INTRODUCTION

Benzene is a widely used chemical compound in the industrialized world, mainly in the combustion of machines and petroleum industry. It is a colorless liquid with a sweet smell, slightly water soluble and it easily evaporates in the air. It is quickly flammable and consists of both natural processes and human activities (ATSDR, 2011).

Exposure to benzene vapors by inhalation or ingestion could affect peoples' health (Zamanian, 2018). It has a negative impact on eyes, skin, airway, nervous system, and lungs. Also, it can cause blood cancers, like leukemia (CDC, 2019). Workers may be affected during exposure to benzene and the level of exposure depends on the dose, duration, and work type (CDC, 2019).

Benzene is easily absorbed following inhalation or oral exposure (Cooper, K.R, et al. 2017), then, it is distributed everywhere in the body following absorption into blood. Since benzene is lipophilic, a high distribution to fatty tissue might be predicted (Meng L, et al.2017). Benzene is metabolized to a multiple of reactive types, and more stable molecules that are secreted in urine (mainly phenol) important concentrations of the phenolic compounds (phenol, catechol and hydroquinone) are detected in human urine, even in the absence of prominent exposures to benzene (Rappaport SM, et al. 2013).

The metabolism of benzene to its toxic metabolites is commonly considered a key factor in the toxicity of benzene. It induces several toxic metabolites that cause hematotoxicity and leukaemia and causes cytogenetic modifications and induces chromosomal aberrations. Also, it has been related to higher levels of chromosomal adjustments often found in AML (Acute Myeloid Leukemia). Benzene bio activation may result in the formation of hazardous metabolites like phenol, hydroquinone, and catechol, 1,2,4-benzenetriol,and 1,2 and 1,4 benzoquinone. Catechol forms semiquinones and reactive quinones presumed to play a significant role in the generation of reactive oxygen species (ROS). ROS formation can directly cause single- and double-strand breaks in DNA, oxidized nucleotides and hyper-recombination, resulting in deleterious genetic alterations (Barreto, G. et al. 2009) (Short et al., 2006) (Agrawal et al., 2001).

Benzene works by inducing the cells to work improperly. also, it causes failing in the bone marrow to produce enough red blood cells (CDC. 2018), and reducing the percentage of iron that is incorporated into the cells which Benzene inhibits the incorporation of Fe into developing erythrocytes and that is dose-dependent manner and inhibition happens after 48 hours of the administration benzene dose (Medinsky etal.,1994). Additionally, hydroquinone is playing an important role in decreasing iron uptake than phenol (Guy et al., 1991). Besides, the concentration of hydroquinone leads to release iron from ferritin, and causes decrease the ferritin by electron transfer which may have toxicological implications in relation to benzene toxicity.

In addition, it causes gene-duplicating mutations in the peripheral red blood cells of exposed humans at the locus of glycophorin A. Moreover, Benzene-induced leukemia is believed to be triggered as benzene metabolites attack genes or pathways that are essential to hematopoiesis in Hematopoietic Stem Cells HSC. Also, it induces cytogenetic modifications such as aneuploidy, which can contribute to altering expression of genes Methylation and translocations of DNA that create chimeric oncoproteins (Mchale et al., 2012).

Therefore, the hematopoietic system is the most sensitive target tissue in either human following exposure to benzene by inhalation. Because it leads decrease in the number of three major components of blood, erythrocytes (anemia), leukocytes (leukopenia) and platelets (thrombocytopenia). also, it causes pancytopenia and plastic anemia (Arnold, S. M.et al.2013).

This study focuses on the effect of benzene exposure on ferritin and complete blood count (CBC) in OiLibya420 gas station workers.

Aim: To evaluate the effect of benzene exposure on ferritin and complete blood count among workers at OiLibya420 Gas Station, Benghazi, Libya.

MATERIALS AND METHODS

Study site: The study was conducted at the OiLibya420 Gas Station in Benghazi, Libya.

Study design: The design of this study cross-sectional approach.

Method of data collection: The data was collected by two ways; multiple choice questionnaires and blood samples. The questionnaire contains thirteen questions, with five of these questions asking general information (include gender, age, years of experience, and level of education). The remaining eight questions are about acute and chronic effects of benzene exposure. And blood samples were withdrawal from participants to test renal and liver functions and well as to determine the level of ferritin in serum and to test Complete Blood Counts (CBC). these data were gathered between July to august 2020.

Target population and sample size

The total number of participants was 32; 16 exposed workers in filling station and 16 non exposed participants. The sample was selected randomly.

Statistical analysis

All date were analyzed using SPSS version 22. Frequency and percentage were calculated. Also, the Mann-Whitney test and the Kruskal-Wallis tests were used to test the relationship between some of the variables.

Ethical consideration

This study began after obtaining approval from the station manager and obtaining permission from the laboratory director.

Limitation

The limitations of this study included the research topic being rejected by the director of the Al-Brega Company for Oil Marketing, who believed that taking blood samples from the workers at the Ras Al-Elmengar warehouse would expose them to other risks, so the study site was changed to a petrol station.

RESULTS AND FINDINGS

The results of this study will be represented into 3 parts: descriptive analysis, analysis of ferritin, and CBC.

3.1 Descriptive analysis:

The table 1 shows that the sample is divided into two groups: cases (exposed workers) and control (non exposed workers). The exposed subjects were all males (16 workers), while in the control group there were 10 males and 6 females. Furthermore, the ages of the most exposed participants between 20-30 years and 41-50 years old.

Table 1: sociodemographic information of exposed and non-exposed groups

Characteristics		No. (%) Exposed group	No. (%) Non-exposed group
Gender	Male	16	10
	Female	0	6
Age	20-30	7	3
	31-40	2	2
	41-50	4	4
	51-60	3	7

Besides, table 2 indicated shows the highest percentage (56%) of exposed workers working in the station had of experience between 1 to 5 years of work experience, while the next highest percentage (25%) had 16 to 20 years work experience. Additionally, it shows that the highest percentage of workers (50%) had a preparatory educational qualification, while the lowest percentage (6%) had a bachelor's degree. And the highest percentage of exposed workers are smokers (56%), 38% of the exposed workers never smoke and 6% were previous smokers. Furthermore, it reports that the most common symptom that exposed group suffer from it were sleeping disturbances and headaches.

Print ISSN: 2517-276X
Online ISSN: 2517-2778
Website: https://bjmas.org/index.php/bjmas/index
Published by European Centre for Research Training and Development UK

Table 2: characteristics of exposed workers to benzene

Characteristics			No. (%) Exposed group
Years of experience		0-5	9 (56.3%)
		6-10	1 (6.3%)
		11-15	0 (0%)
		16-20	4 (25%)
		21-25	0 (0%)
		More than 26	2 (12.5%)
Qualification level		Preparatory	8 (50%)
		High school	3 (18.8%)
		Diploma	4 (6.3%)
		BSc	1 (25%)
Smoker		Never	6 (37.5%)
		Current smokers	9 (56.3%)
		Pervious smoker	1(6.3%)
Symptoms	drowsiness	Yes	0
		No	16
	dizziness	Yes	1
		No	15
	exhaustion	Yes	2
		No	14
	headache	Yes	5
		No	11
	tremors	Yes	2
		No	14
	confusion	Yes	2
		No	14
	sleepiness	Yes	5
		No	11
	consciousness	Yes	3
		No	13

Ferritin analysis:

Compared to the normal range of the level of ferritin in serum of 15 - 232 ng/ml, the results of figures 1 show normal levels of ferritin for most of the control participants, and most of the case participants with normal to deficient levels.

Serum Ferritin Level

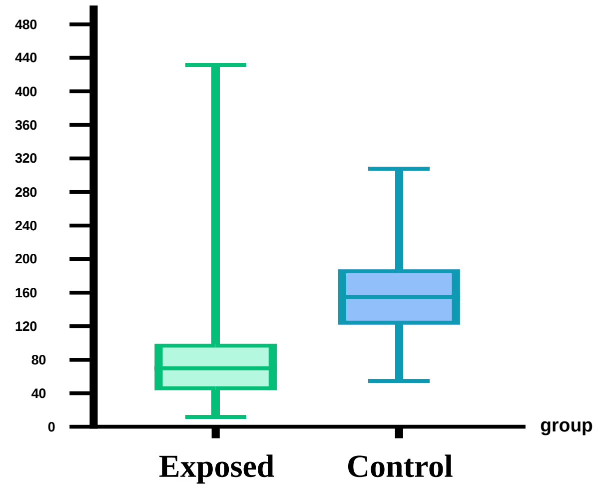

Figure 1: Ferritin levels in exposed and non-exposed groups

Furthermore, the next table shows that there is no statistical relationship between serum ferritin levels among exposed and non-exposed group because the p-value was greater than 0.05.

Table 3: Association between serum ferritin in exposed and non-exposed groups using Mann-Whitney Test

	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig.
Serum Ferritin	95.000	231.000	-1.244	0.214

Table 4 shows no relationship between the educational qualification of workers in station and serum ferritin since the significant value was higher than (0.05).

British Journal of Multidisciplinary and Advanced Studies:
Earth Sciences 5 (3),1-23, 2024
Print ISSN: 2517-276X
Online ISSN: 2517-2778
Website: https://bjmas.org/index.php/bjmas/index
Published by European Centre for Research Training and Development UK

Table 4: Association between serum ferritin and qualification levels using Kruskal-Wallis Test.

	Chi-Square	df	Asymp. Sig.
Serum Ferritin	1.564	3	0.668

Also, there is no relationship between the workers' years of experience and their ferritin serum levels because the significance value was greater than 0.05 (see table 5).

Table 5: Association between serum ferritin and years of experience using Kruskal-Wallis Test.

	Chi-Square	df	Asymp. Sig.
Serum Ferritin	3.585	3	0.310

Table 6: shows the existence of a relationship between workers' age and serum ferritin in their body, where the significant value was found to be less than (0.05).

Table 6: Association between serum ferritin and workers' ages using Kruskal-Wallis Test

	Chi-Square	df	Asymp. Sig.
Serum Ferritin	7.871	3	0.049

Table 7 shows that there is no relationship between smoking and the level of serum ferritin, where the significance value was greater than (0.05).

Table 7: Association between serum ferritin and smoking using Kruskal-Wallis Test.

	Chi-Square	df	Asymp. Sig.
Serum Ferritin	1.431	2	0.489

Analysis of Complete blood counts:

Regarding the CBC test of both groups, figure 2 shows that the hemoglobin levels of the exposed people were within normal ranges, and therefore, there is no effect compared to the non-exposed.

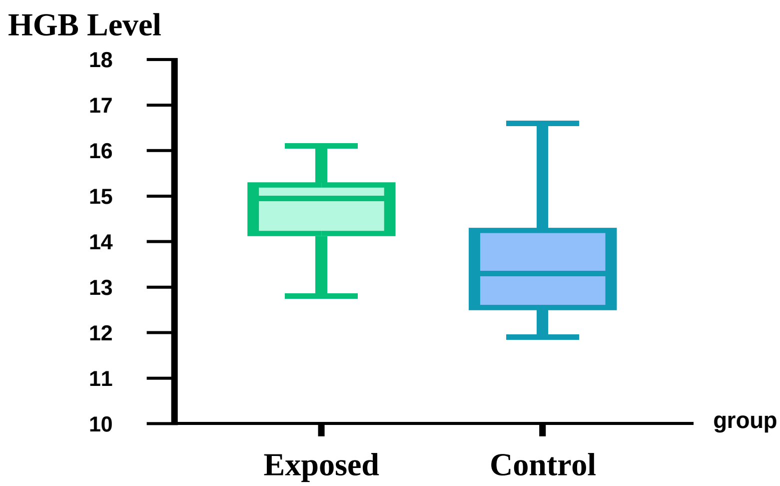

Figure 2: HGB level of exposed and non-exposed groups

Figure 3 shows that there is a difference in the levels of WBC between exposed and non-exposed, as it reveals an increase in the levels of WBC among the exposed, considering the value of the median shown by the boxplot.

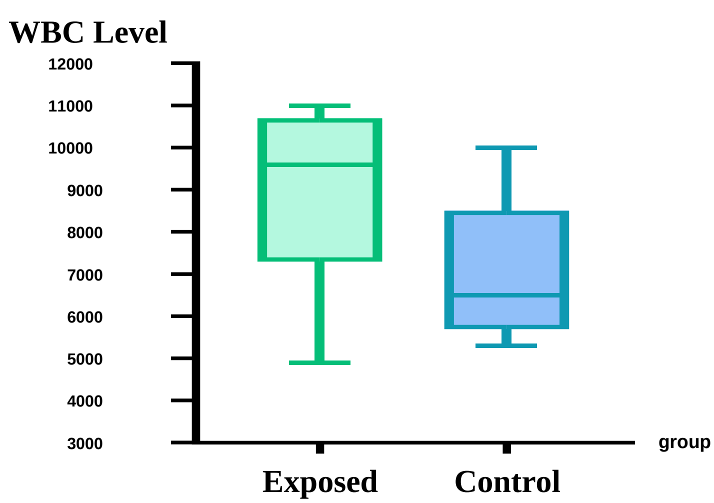

Figure 3: WBC level of exposed and non-exposed groups

British Journal of Multidisciplinary and Advanced Studies:
Earth Sciences 5 (3),1-23, 2024
Print ISSN: 2517-276X
Online ISSN: 2517-2778
Website: https://bjmas.org/index.php/bjmas/index
Published by European Centre for Research Training and Development UK

Figure 4 shows that there is a difference in the levels of RBC between exposed and non-exposed, as there is an increase in the levels of RBC in exposed compared to non-exposed.

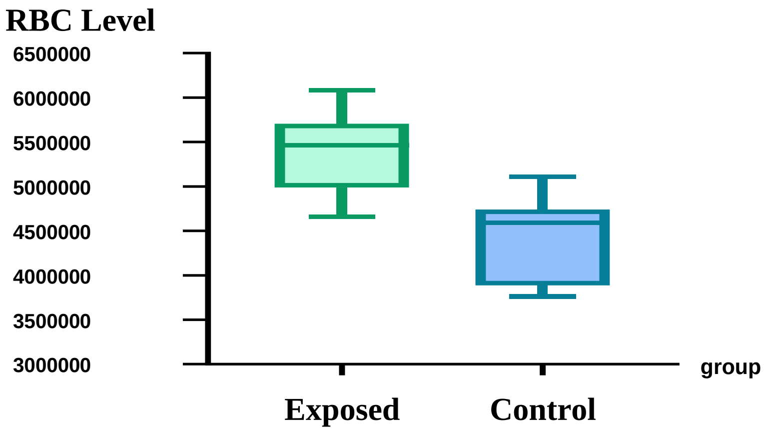

Figure 4: RBC level of exposed and non-exposed groups

Regarding the PLT levels, an increase in the level of PLT among the exposed persons compared with the non-exposed is noted, as the largest value reached 500000, which signals an effect (see figure 5).

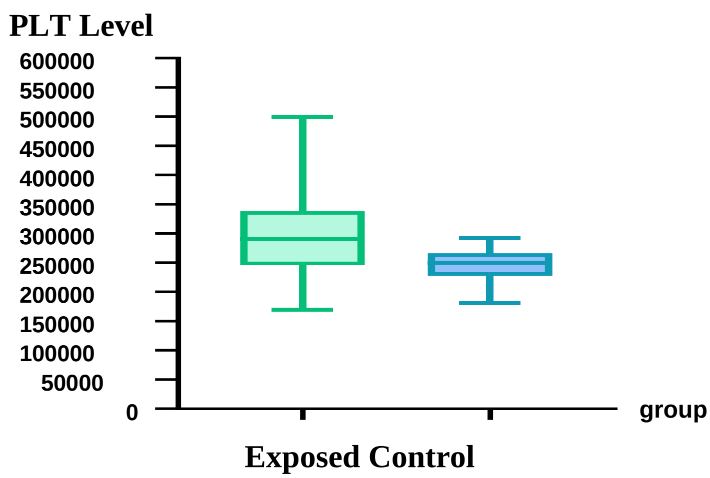

Figure 5: PLT level of exposed and non-exposed groups

Figure 6 shows that HCT levels in both exposed and nonexposed groups were within the normal range.

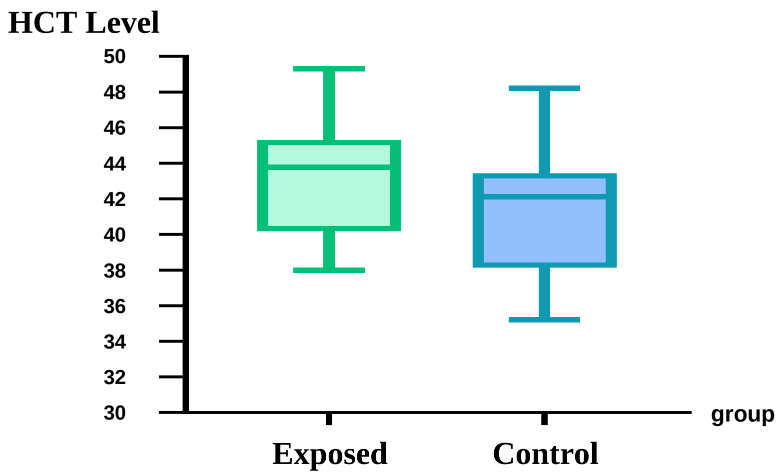

Figure 6: HCT level of exposed and non-exposed groups

Figure 7 shows that the MCV levels in both exposed and non-exposed groups were different as there was a decrease in the MCV level of exposed compared to the normal range of 80-100.

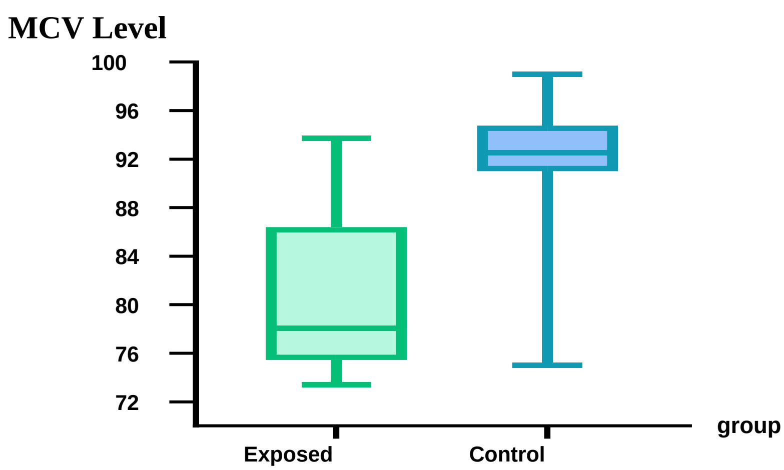

Figure 7: MCV level of exposed and non-exposed groups

Additionally, figure 8 indicates that the MCH levels of those exposed were lower than the normal range (27-33) with a median low for those exposed.

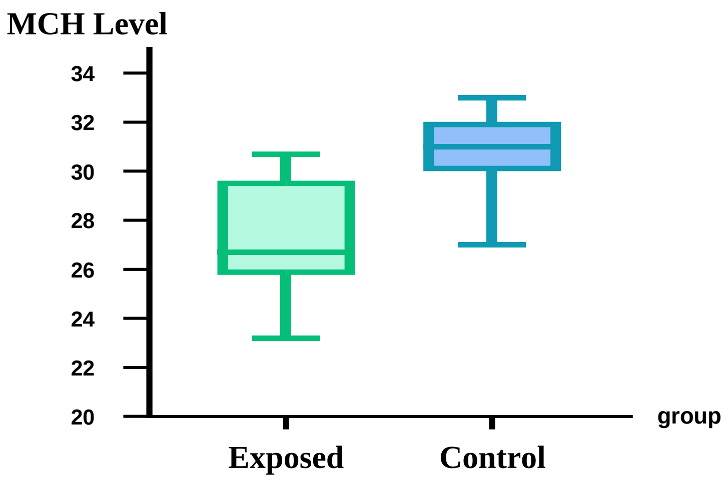

Figure 8: MCH level of exposed & non-exposed groups

Most of the exposed participants' MCHC levels are within the normal range, with some of the respondents having readings from the smallest levels (23) and largest values (37) (Figure 9).

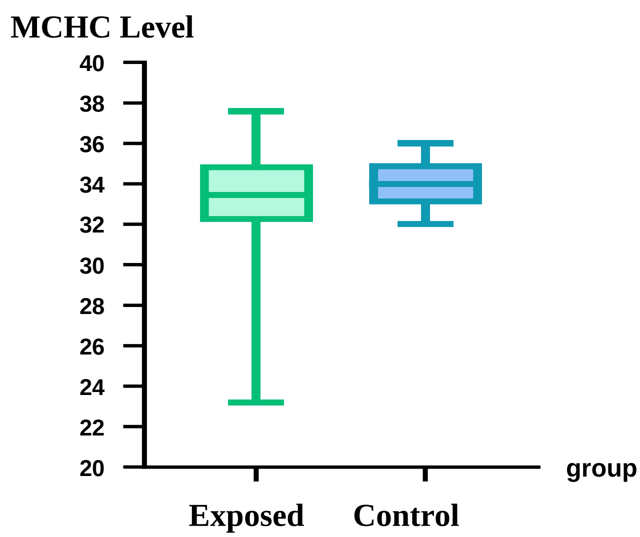

Figure 9: MCHC level of exposed & non-exposed groups

British Journal of Multidisciplinary and Advanced Studies:
Earth Sciences 5 (3),1-23, 2024
Print ISSN: 2517-276X
Online ISSN: 2517-2778
Website: https://bjmas.org/index.php/bjmas/index
Published by European Centre for Research Training and Development UK

Furthermore, LYM levels of exposed compared to non-exposed are considered within the normal range of 20% -40% (see figure 10). Furthermore, figure 11 shows that MXD levels are different between exposed and non-exposed.

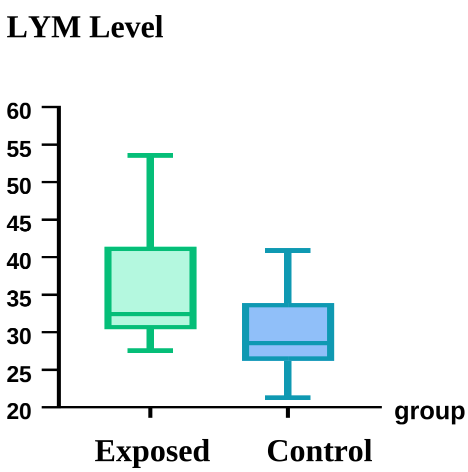

Figure 10: LYM level of exposed & non-exposed groups

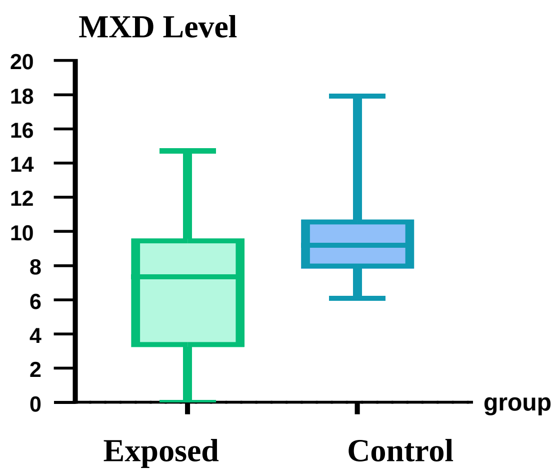

Figure 11: MXD level of exposed and non-exposed groups

Moreover, there is an increase in the level of Neut. for exposed and nonexposed, compared to the normal range of 40% -60% (see figure 12).

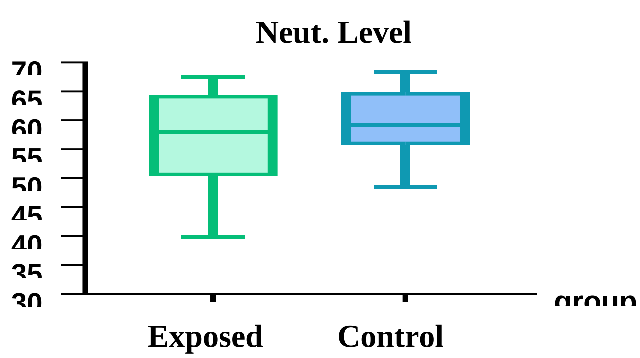

Figure 12: Neut. level of exposed and non-exposed groups

British Journal of Multidisciplinary and Advanced Studies:
Earth Sciences 5 (3),1-23, 2024
Print ISSN: 2517-276X
Online ISSN: 2517-2778
Website: https://bjmas.org/index.php/bjmas/index
Published by European Centre for Research Training and Development UK

In summary, table 8 illustrates that there is a statistical relationship between WBC, RBC, HGB, MCV, MCH, LYM and MXD levels among exposed & non-exposed participants, because the p values were less than 0.05. Conversely, there is no relationship between HCT, MCHC, PLT and Neut values among exposed & non-exposed, as shown by the p values greater than 0.05.

Table 8: Association between complete blood counts and exposed and non-exposed groups using Mann-Whitney Test

Blood parameters	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig.
WBC	73	209	-2.075	0.038
RBC	15	151	-4.26	0.000
HGB	83	219	-1.699	0.089
HCT	85	221	-1.621	0.105
MCV	34.5	170.5	-3.527	0.000
MCH	17.5	153.5	-4.184	0.000
MCHC	117.5	253.5	-0.398	0.690
PLT	86	222	-1.583	0.113
LYM	71	207	-2.149	0.032
MXD	69.5	205.5	-2.206	0.027
NEUT	100	236	-1.055	0.291

Table 9 shows no relationship between the qualification level of workers and the complete blood counts, as p values are greater than 0.05, except for MCH with its p values equal to 0.05.

Table 9: Association between complete blood count and qualification levels using Kruskal-Wallis Test

Blood parameters	Chi-Square	Df	Asymp. Sig.
WBC	3.679	3	0 .298
RBC	3.948	3	0.267
HGB	1.597	3	0.660
HCT	.501	3	0.919
MCV	5.783	3	0.123
MCH	7.647	3	0.054
MCHC	1.509	3	0.680
PLT	5.017	3	0.171
LYM	2.952	3	0.399
MXD	3.319	3	0.345
NEUT	1.373	3	0.712
LYMM	0.470	3	0.925
MXDD	6.259	3	0.100
NEUTT	2.045	3	0.563
RDWSD	4.547	3	0.208
RDWSV	3.784	3	0.286
PDW	2.415	3	0.491
MPV	3.400	3	0.334
PLCR	2.692	3	0.442
PCT	4.078	3	0.253

Table 10 shows a positive correlation between years of experience and WBC, LYMM and PCT level of exposed workers, with p values less than 0.05. However, there is no relationships observed in the rest because p values were greater than 0.05.

Table 10: Association between complete blood count and years of experience using Kruskal-Wallis Test

Blood parameters	Chi-Square	df	Asymp. Sig.
WBC	8.612	3	0.035
RBC	3.672	3	0.299
HGB	3.349	3	0.341
HCT	2.988	3	0.394
MCV	1.490	3	0.685
MCH	3.487	3	0.323
MCHC	5.628	3	0.131
PLT	1.809	3	0.613
LYM	3.473	3	0.324
MXD	2.439	3	0.486
NEUT	1.456	3	0.692
LYMM	6.907	3	0.075
MXDD	2.975	3	0.395
NEUTT	3.037	3	0.386
RDWSD	0.851	3	0.837
RDWSV	1.144	3	0.766
PDW	3.269	3	0.352
MPV	1.577	3	0.665
PLCR	1.705	3	0.636
PCT	7.630	3	0.54

Table 11 shows no relationship between workers' ages and complete blood count because p values were greater than 0.05, except HGB.

Table 11: Association between complete blood count and workers' age using Kruskal-Wallis Test

Blood parameters	Chi-Square	df	Asymp. Sig.
WBC	0.982	3	0.806
RBC	1.644	3	0.649
HGB	9.962	3	0.019
HCT	3.658	3	0.301
MCV	2.543	3	0.468
MCH	4.457	3	0.216
MCHC	5.602	3	0.133
PLT	5.223	3	0.156
LYM	5.070	3	0.167
MXD	0.471	3	0.925
NEUT	3.757	3	0.289
LYMM	3.624	3	0.305
MXDD	0.193	3	0.979
NEUTT	4.170	3	0.244
RDWSD	4.151	3	0.246
RDWSV	4.268	3	0.234
PDW	4.762	3	0.190
MPV	4.758	3	0.190
PLCR	4.846	3	0.183
PCT	2.673	3	0.445

As shown in table 12 there is no relationship between smoking & complete blood count because p values are greater than 0.05.

Table 12: Association between complete blood count and smoking using Kruskal-Wallis Test

	Chi-Square	Df	Asymp. Sig.
WBC	1.579	2	0.454
RBC	0.837	2	0.658
HGB	2.441	2	0.295
HCT	2.172	2	0.338
MCV	5.471	2	0.065
MCH	2.843	2	0.241
MCHC	0.118	2	0.943
PLT	0.971	2	0.616
LYM	2.274	2	0.321
MXD	0.550	2	0.760
NEUT	2.059	2	0.357
LYMM	3.873	2	0.144
MXDD	0.028	2	0.986
NEUTT	4.274	2	0.118
RDWSD	1.229	2	0.541
RDWSV	1.709	2	0.426
PDW	0.820	1	0.365
MPV	1.081	1	0.298
PLCR	1.114	1	0.291
PCT	0.000	1	1.0

DISCUSSION

Effects of benzene exposure on ferritin

This study found a deficiency in the serum ferritin levels of exposed group**.** Also, it showed the existence of a relationship between workers' age and serum ferritin of workers who exposed to benzene. This is a new finding compared to previous studies, as no previous research discussed the relation between workers age and serum ferritin. Besides, the present study showed no relationship between the workers' years of experience and their ferritin serum levels.

As well as no relationship between the educational qualification of exposed workers in station and their serum ferritin levels. No previously published studies assessed the correlation between the years of experience, educational level of exposed workers in station and their serum Ferritin levels. Additionally, no correlation between smoking and the level of serum ferritin was reported, and there is no previously published study that discussed this relationship.

Effects of benzene exposure on CBC

This study showed an effect on the WBC, RBC, and PLT caused by exposure to benzene, as they were found at increased blood levels. Also, it showed effects in HGB, HCT, LYM and Neut. Additionally, there was a decrease in the levels of MCV, MCH, and MCHC, as well as MXD. Another previously published study reported that the means of red blood cell count, hemoglobin, and hematocrit were significantly higher in the exposed group compared to the unexposed one, while the platelet count was found significantly lower in the exposed group than in the unexposed group. Also, it found that the proportion of red blood cell volume and lymphocyte was significantly lower in the exposed group than in the unexposed group (Cao et al., 2018). Moreover, Khuder et al. (1999) found a substantial decrease in the complete blood count of the workers who were exposed to benzene doses ranging between 0.14 parts per million and 2.08 parts per million (8-hour time-weighted average 0 from 1967 to 1994) (Khuder et al., 1999).

Alongside this, Koh et al. reported a strong negative association between low-level benzene and RBC counts in male exposed workers, with no clear correlation between low-level benzene exposure and WBC, platelet, neutrophil, and lymphocyte counts (Koh et al., 2015).

On the other hands, the results of current study showed no relationship between workers' age and the effects of benzene on CBC. This comes in disagreement with James, J. et al., which they indicated that the RBC were affected by age during exposure to benzene, from where it can be inferred that increases in age correlated with decrease RBC counts, and MCV appeared to increase exponentially with age among persons with exposure from 0.01 ppm to a high 1.40 ppm 8-hour time weighted average over 10-year period (Collins, et al., 1991).

Furthermore, the present study showed no relationship between smoking and the effects of benzene on CBC. In contrast, James et al. found that the WBC, RBC, PLT and MCV count increase among the exposed workers who are smokers (Collins et al., 1991). Moreover, the present study revealed a relationship between the years of experience of workers and the WBC, LYM and PCT levels of exposed workers to benzene. Collins et al., (1999) showed that there was a relationship between the working years and the effects of benzene on CBC of workers who had over 10 years' experience (Collins et al., 1991). On the other hands, this study showed no relationship between the qualification level and CBC except for the MCH. while no previously published epidemiologic study that relationship.

CONCLUSION

The ferritin is affected by exposure to benzene in the workplace, and no relationship between the ferritin levels of exposed workers and their educational and qualification levels, years of experience and smoking status, while there is an association between workers' age and serum ferritin in their body. In addition, there are clear effects of benzene on the WBC, RBC, HGB, MCV, MCH, LYM and MXD levels of workers who were exposed to benzene. And there is a positive correlation between working length and benzene effects on WBC and PCT. And a negative relationship between the qualification levels of workers and the effects of benzene on complete blood counts, with the exception of MCH. The study did not show any association between the age of exposed workers and the effect of benzene on CBC, except for HGB. There is no relationship shown between workers' smoking status and the effects of benzene on their blood. Therefore, it recommended to educate and train workers about the hazards of gasoline and its effects on health, as well as the importance of monitoring and prevention., and provide medical checks for workers every 6 months to monitor the early effects of benzene exposure and provide protective equipment that must be worn by every worker while working, in accordance to the standard of the World Health Organization. This standard includes the use of goggles, boots, gloves, and mask respirators such as air- purifying respirator.

Conflict of interest

None declared.

Funding

None.

References

Agrawal, R., Sharma, P. K., & Rao, G. S. 2001. Release of iron from ferritin by metabolites of benzene and superoxide radical generating agents. Toxicology, 168(3), 223-230.

Arnold, S. M., Angerer, J., Boogaard, P. J., Hughes, M. F., O'Lone, R. B., Robison, S. H., & Robert Schnatter, A. (2013). The use of biomonitoring data in exposure and human health risk assessment: benzene case study. Critical reviews in toxicology, 43(2), 119-153.

ATSD, 2011. *Benzene* Available Online at https://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=14

Barreto, G., Madureira, D., Capani, F., Aon-Bertolino, L., Saraceno, E., & Alvarez-Giraldez, L. D. 2009. *The role of catechols and free radicals in benzene toxicity: an oxidative DNA damage pathway*. Environmental and molecular mutagenesis, *50*(9), 771-780.

Cao, Y. M., Gao, W. M., & Liu, J. 2018. Study on the health effects of occupational exposure to low concentrations of benzene. Zhonghua lao dong wei sheng zhi ye bing za zhi= Zhonghua laodong weisheng zhiyebing 61 zazhi= Chinese journal of industrial hygiene and occupational diseases, 36(6), 435-438.

CDC. 2019. *Benzene* Available Online at https://www.cdc.gov/niosh/topics/benzene/

CDC. 2018. *Facts about Benzene* Available Online at https://emergency.cdc.gov/agent/benzene/basics/facts.asp?fbclid=IwAR3hLHjOE7K3eEq6IiOSVeBzmaSPID0ZOQoU06gdnQTmsljcm6l6ra9ns7A

Cooper, K. R., & Snyder, R. 2017. *Benzene metabolism (toxicokinetics and the molecular aspects of benzene toxicity). In Benzene carcinogenicity* (pp. 33-58). CRC Press.

Guy, R. L., Hu, P., Witz, G., Goldstein, B. D., & Snydert, R. 1991. Depression of iron uptake into erythrocytes in mice by treatment with the combined benzene metabolites p-benzoquinone, muconaldehyde and hydroquinone. Journal of applied toxicology, 11(6), 443-446.

Khuder, S. A., Youngdale, M. C., Bisesi, M. S., & Schaub, E. A. 1999. Assessment of complete blood count variations among workers exposed to low levels of benzene. Journal of occupational and environmental medicine, 41(9), 821-826.

Koh, D. H., Jeon, H. K., Lee, S. G., & Ryu, H. W. 2015. The relationship between low-level benzene exposure and blood cell counts in Korean workers. Occupational and environmental medicine, 72(6), 421-427.

McHale, C.M., Zhang, L. and Smith, M.T., 2012. Current understanding of the mechanism of benzene-induced leukemia in humans: implications for risk assessment. Carcinogenesis, 33(2), pp.240-252.

Medinsky, M. A., Schlosser, P. M., & Bond, J. A. 1994. Critical issues in benzene toxicity and metabolism: the effect of interactions with other organic chemicals on risk assessment. Environmental Health Perspectives, 102(suppl 9), 119-124.

Meng, L., Zhu, X., & Hensen, E. J. 2017. *Stable Fe/ZSM-5 nanosheet zeolite catalysts for the oxidation of benzene to phenol*. ACS catalysis, 7(4), 2709-2719.

Mohamed, H., Swani, M. A., Alaghib, M. I., Abdeljawad, A. I., Alkezza, M., & Alobaidy, M. 2017. Hematological Assessment of Benzene Exposure among Employees in Brega Oil Marketing Company (BOMC), Benghazi. International Blood Research & Reviews, 1-7.

Rappaport, S. M., Kim, S., Thomas, R., Johnson, B. A., Bois, F. Y., & Kupper, L. L. 2013. *Low-dose metabolism of benzene in humans: science and obfuscation. Carcinogenesis*, 34(1), 2-9.

Zamanian, Z., Sedaghat, Z., & Mehrifar, Y. 2018. *Harmful outcome of occupational exposure to petrol: Assessment of liver function and blood parameters among gas station workers in Kermanshah city, Iran.* International journal of preventive medicine, 9.