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Original article

Hematological and Biochemical Effects of Occupational Ionizing Radiation Exposure Among Radiology Workers in Western Libya

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Abstract
Occupational exposure to ionizing radiation may pose potential health hazards to radiology staff, particularly in areas with limited radiation safety monitoring. Thus, the current study aimed to compare changes in the hematological and biochemical parameters of healthcare workers with their corresponding controls. A cross-sectional study was carried out between October 2024 and March 2025, comprising 109 participants, including an exposed group (n=50) and a control group (n=59). Hematological parameters and liver function markers were analyzed. Statistical comparisons were performed using independent *t*-tests. The results revealed significant differences in platelet count (P =0.001), hemoglobin (P =0.002), mean corpuscular hemoglobin MCH (P =0.006), and mean corpuscular hemoglobin concentration MCHC (P <0.001). The occupationally exposed group showed a reduced platelet count and increased hemoglobin indices compared with the control group. Biochemical analysis also showed a significant decrease in direct bilirubin levels (P =0.005), whereas no significant differences were revealed in other biochemical parameters. These findings suggest that chronic occupational exposure to ionizing radiation may be associated with subtle hematological and biochemical alterations among radiology staff. Regular monitoring and improved radiation safety practices are recommended to reduce potential risks.
Keywords. Ionizing Radiation, Radiology Workers, Occupational Exposure, Hematology, Liver Function, Libya.

Introduction
Medical radiation comprises energy transmitted through space in waves or particles. It is classified into ionizing and non-ionizing radiation according to its ability to ionize atoms within biological tissues [1]. Despite its significant benefits in healthcare, occupational exposure to ionizing radiation continues to be a concern for radiology workers who are regularly exposed to low-dose radiation during their professional activities [1]. Ionizing radiation causes significant cellular damage through both direct DNA ionization and indirectly via generation of reactive oxygen species (ROS), causing molecular damage [2,3]. High-dose radiation exposure may induce acute radiation syndrome manifested by gastrointestinal, hematopoietic, and skin injury [3,4]. However, chronic repeated low-dose exposure has been linked with the risk of cancer, cataracts, genetic mutations, cardiovascular disease, and hematological abnormalities [5,6]. Additionally, long-term exposure to low doses may impair immune function and induce hematological alterations [2, 3].
Previous studies have reported reductions in red blood cell count (RBC), hemoglobin (Hb), white blood cells (WBC), and platelet count (PLT), along with alterations in other hematological indices, suggesting that long-term occupational exposure to ionizing radiation may adversely affect the hematopoietic system [7-11]. Similarly, a recent study demonstrated that chronic occupational exposure to low dose radiation was associated with measurable alterations in hematological parameters among medical workers, supporting their use of these parameters as early indicators of radiation-induced biological effects [12].
Beyond the hematopoietic abnormalities, chronic radiation exposure has also been associated with biochemical alterations among radiation-exposed workers. Several studies have reported alterations in hepatic enzyme activities, suggesting possible hepatic dysfunction following long-term occupational exposure [13,14]. These findings highlight the necessity of continuous health surveillance and strict radiation safety measures for occupationally exposed personnel. However, data regarding the biological effects of occupational radiation exposure among radiology workers in Libya is limited. Therefore, the current study aimed to evaluate the value of some hematological and biochemical parameters among workers occupationally exposed to chronic ionizing radiation in Western Libya and to identify potential biomarkers of radiation-induced toxicity.

Methods
Data collection
A cross-sectional study was carried out from October 2024 to March 2025 to evaluate the occupational health impacts of chronic radiation exposure. A total of 109 participants were recruited and categorized into two groups: an exposed group comprised of occupationally radiation-exposed employers who had been occupationally exposed to radiation for a minimum of 10 years (n=50) and a healthy control group with no previous history of exposure (n=59).

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Questionnaire Design

Data were collected using structured questionnaires designed to obtain demographic and occupational information. They included comprehensive information, including age, gender, smoking status, medical history, and relevant occupational variables, including job role, duration of occupation, and adherence of safety procedures.

Laboratory and Biochemical Analyses

Hematological analysis

For hematological analysis, 2-3ml of venous blood was collected in EDTA-containing tubes and labeled with the patient's name, ID, and time of collection. Subsequently, the samples were analyzed within a few hours (2-4 hours of sampling) using a Sysmex XP-300 hematology analyzer. Measured parameters included red blood cell count (RBC), white blood cell count (WBC), hemoglobin concentration (Hb), hematocrit (HCT), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), and platelet count (PLT).

Biochemical analysis

Approximately 5 mL of blood was collected into a serum tube. This tube does not contain an anticoagulant and was centrifuged at 3000 rpm for 10 minutes. Then serum samples were frozen at - 20°C until analyzed. The activities of liver enzymes such as alanine aminotransferase (ALT), aspartate aminotransferase (AST), alkaline phosphatase (ALP), total bilirubin (T.B), and direct bilirubin (D.B) were measured using automated chemistry analyzers.

Statistical analysis

The data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 20. Descriptive statistics were illustrated as frequency, percentages, means, and standard deviations. To compare quantitative data between radiation-exposed and control groups, t-test analysis was used. A *p*-value < 0.05 was considered statistically significant.

Ethics approval and consent to participate

Ethical approval was obtained from the relevant institutional authorities. Written informed consent was obtained from all participants prior to inclusion in the study.

Results

Demographic characteristics of exposed group & control group

As shown in (Table 1), the majority of participants in both groups were aged 42 - 88 years, accounting for 76.3% of the control group and 78% of the exposed group. Males constituted most participants in both groups, representing 61.02% of the control group and 80% of the exposed group. Across the exposed group, 54% held a diploma, 34% had a bachelor's degree and 12%, a master's degree. Nearly half of the exposed group 48% were employed in both public and private hospitals, while 28% worked in private hospitals and 24% worked only in public hospitals. Forty percent (40%) of exposed participants had occupational experience for 16-27 years. The prevalence of smoking was higher among exposed workers 56% than controls, whereas diabetes mellitus was reported only in 22% of exposed workers. Additionally, the majority of radiation-exposed participants reported not wearing Personal Protective Equipment (PPE) during work, whereas only 20% did.

Table 1. Demographic and occupational characteristics of the study participants. (35)

Varaiable	Control	Exposed
Age, n (%)		
Age 27-31	3 (5.1)	1 (2.0)
Age 32-36	7 (11.9)	5 (10.0)
Age 37-41	4 (6.8)	5 (10.o)
Age 42-88	45 (76.3)	39 (78.0)
Gender n (%)		
Male	36 (61.0)	40 (80.0)
Female	23 (39.0)	10 (20.0)
Smoking status, n (%)	27 (45.0)	28 (56.0)
Diabetes mellitus, n (%)	21 (35.6)	11 (22.0)
PPE use, n (%)	_	10 (20.0)
Educational levels, n (%)		
Diploma	_	27 (54.0)
Bachalore's	_	17 (34.0)
Master	_	6 (12.0)
Public	_	12 (24.0)

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Work places, n (%)		
public	_	12 (24.0)
Private	_	14 (28.0)
Public and private	_	24 (48.0)

Quantitative and inferential result

The results of the analyzed blood parameters revealed statistically significant differences between the control and ionizing radiation-exposed groups as shown in (Table 2). The exposed group, exhibited significantly higher mean values of MCHC ($P < 0.001$), Hb ($P = 0.002$, and MCH ($P = 0.006$). However, platelet count was significantly lower in the exposed group, $P = 0.001$. No significant differences were revealed in hematocrit, WBC, RBC count, or MCV, $P > 0.05$. As shown in (Table 3), no statistically significant differences were observed between the exposed and control groups in most hepatic biochemical parameters, including ALP, ALT, AST, and total bilirubin (T.B.) $P > 0.05$. However, direct bilirubin (D.B.) was significantly different between the groups $P = 0.013$, suggesting that occupational radiation exposure may induce subtle changes in liver function. (Table 4) shows the comparison of hematological and biochemical parameters between exposed and control groups based on workplace. Significant differences were observed in Hb, HCT and RBC counts ($P < 0.05$). The lowest mean value of these parameters was demonstrated in participants employed in public hospitals. Conversely, no significant differences were found in WBC count, erythrocyte indices (MCV, MCH, and MCHC), platelet count, ALP, AST, ALT, total bilirubin (T.B.), and direct bilirubin (D.B.) across different workplaces, P > 0.05. Gender – specific comparison are summarized in (Table 5).

Table 2. Comparison of hematological parameters between control group n (59) and exposed group (50)

Blood Parameter	Control Group Mean± SD (SE)	Exposed Group Mean± SD (SE)	*P*-Value
MCHC	32.74±1.37	34.47± 1.90	0.000*
HB	13.66±1.65	14.77± 1.94	0.002*
MCH	28.2±2.30	29.8±3.48	0.006*
WBC	7.45±2.03	7.92±2.27	0.256
HC	41.5±42,9	42.9±4.98	0.111
RBC	4.84±0.49	4.93±0.57	0.339
MCV	84.7±10.37	86.3±9.56	0.406
PLT	274.57±63.23	234.30±65.40	0.001*

**Values are presented as mean ± sd. Indicates significant differences between groups (P < 0.05).*

Table 3. Comparison of biochemical profile between control group (59) and exposed group (50).

Blood Parameter	Control Group Mean± SD (SE)	Exposed Group Mean± SD (SE)	*P*-Value
ALP	90.73± 39.98	89.82±28.19	0.107
ALT	20.0±9.32	18.51±10.15	0.345
AST	18.55±11.08	16.87±5.89	0.338
T. B	0.56±0.23	0.52±0.22	0.314
D.B	0.207±0.094	0.16±0.096	0.013*

**Values are presented as mean ± sd. Indicates significant differences between groups (P < 0.05).*

Table 4. Comparison of hematological parameters among work sites in the exposed group n (50)

Chemistry	work place	Mean	Std. Deviation	One way ANOVA *P* -value
Hb(g/dl)	public	13.13	2.17	0.002*
	Private	15.49	1.79	
	public & private	15.18	1.44	
PCV(HCT)%	public	37.93	4.32	0.000*
	private	45.20	4.01	
	public & private	44.24	4.12	
RBC X $10^3/L$	public	4.59	0.56	0.029*
	Private	5.15	0.71	
	public & private	4.99	0.39	
WBCX$10^3/L$	Public	8.04	2.65	0.975
	Private	7.94	2.35	
	public &private	7.86	2.12	
PLTs $X\ 10^3/L$	Public	262.33	72.81	0.234

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	Private	222.71	70.50	
	public &private	227.04	56.75	
MCV (ft)	Public	83.18	7.57	0.386
	Private	86.39	14.72	
	public &private	87.90	6.10	
MCH (pg/cell)	Public	28.73	3.83	0.341
	Private	29.57	4.25	
	public &private	30.51	2.74	
MCHC (%)	Public	34.43	2.59	0.757
	Private	34.18	1.78	
	public &private	34.66	1.62	
ALP(U/L)	Public	93.87	31.09	0.248
	Private	79.09	18.62	
	public &private	94.07	30.63	
AST(U/L)	Public	22.08	12.77	0.071
	Private	13.36	7.07	
	public &private	19.32	9.50	
ALT(U/L)	Public	18.82	8.24	0.061
	Private	13.82	4.01	
	public &private	17.68	4.91	
T. B (mg/dl)	Public	0.43	0.16	0.226
	Private	0.57	0.26	
	public &private	0.55	0.23	
D. B(mg/dl)	Public	0.16	0.10	0.973

Values are presented as mean ± sd. Indicates significant differences between groups (P** < 0.05).*

The exposed male group showed significantly higher mean values of Hb, MCH, and MCHC, and significantly lower mean values of platelet count and direct bilirubin levels (D.B.) compared with control, $P < 0.05$. The exposed female group had significantly lower mean values of platelet count and direct bilirubin (D.B.) compared with the control group, while no significant differences in Hb, MCHC, or MCH were detected ($P > 0.05$). Correlation analysis (Table 6) showed significant positive associations between age and Hb, RBC, WBC, PLTs count, MCV, MCH, MCHC, ALT, and total bilirubin (T.B.), $P < 0.05$. However, years of occupational exposure were not significantly correlated with any of the investigated hematological or biochemical parameters ($P > 0.05$). Furthermore, significant multiple correlations were revealed between the blood parameters and the predictor variables (age and years of work experience) ($P < 0.001$), as shown in (Table 7). These results suggest that these factors may contribute to variations in hematological and biochemical profiles and should be considered when evaluating the biological effects of chronic radiation exposure.

Table 5. Sex-specific comparison of significant hematological and biochemical parameters between control n (59) and exposed (50) groups.

Blood parameter	**gender**	**Control group Mean± SD (SE)**	**Exposed group Mean± SD (SE)**	***P*-value**
PLTs $X\ 10^3/L$	Female	252.78±65.42	239.20±69.26	0.046*
	Male	288.50±58.51	233.07±65.26	0.000*
MCHC (%)	Female	32.36±1.35	33.32±2.52	0.16
	Male	32.97±1.35	34. 76± 1.60	0.000*
Hb(g/dl)	Female	12.63±1.8	12.43±2.50	0.80
	Male	14.33±1.09	15.36± 1.23	0.000*
MCH (pg/cell)	Female	27.41±2.87	27.82±4.45	0.75
	Male	28.79±1.68	30.31±3.06	0.010*
D. B(mg/dl)	Female	0.19±0.074	0.12±0.081	0.016*
	Male	0.22±0.10	0.17±0.098	0.016*

**Values are presented as mean ± sd. Indicates statistically significant differences between groups (P < 0.05)*

Table 6. Correlation between age, working years, and haematological and biochemical parameters among workers.

Blood parameters	**Variable**	**Coefficients**	***P*-value**	**Relationship**
Hb(g/dl)	Working years	-0.013	0.928	Negative
	Age	0.313	0.000*	Significantly Positive
PCV(HCT)%	Working years	0.032	0.933	Positive

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	Age	0.880	0.000*	Significantly Positive
RBC X $10^3/L$	Working years	-0.010	0.836	Negative
	Age	0.107	0.000*	Significantly Positive
WBCX$10^3/L$	Working years	-0.034	0.758	Negative
	Age	0.181	0.001*	Significantly Positive
PLTs X $10^3/L$	Working years	2.531	0.447	Positive
	Age	3.704	0.019*	Significantly Positive
MCV (ft)	Working years	0.170	0.794	Positive
	Age	1.729	0.000*	Significantly Positive
MCH (pg/cell)	Working years	-0.048	0.848	Negative
	Age	0.644	0.000*	Significantly Positive
MCHC (%)	Working years	-0.063	0.820	Negative
	Age	0.745	0.000*	Significantly Positive
ALP(U/L)	Working years	2.493	0.065	Positive
	Age	0.729	0.238	Positive
AST(U/L)	Working years	0.410	0.367	Positive
	Age	0.192	0.361	Positive
ALT(U/L)	Working years	0.207	0.445	Positive
	Age	0.257	0.044*	Significantly Positive
T. B (mg/dl)	Working years	-0.005	0.630	Negative
	Age	0.013	0.007*	Significantly positive
D. B(mg/dl)	Working years	0.005	0.290	positive
	Age	0.001	0.521	positive

**Values represent correlation coefficients (r). Significant correlation was considered at (P < 0.05).*

Table 7. Dependent variable blood parameter and predictors age and working years

Exposed Blood Parameter	Multiple correlation	***P*** -value	Conclusion
Hb (g/dl)	0.976	0.000*	Significant correlation HB and (age, working years) together
PCV(HCT)%	0.978	0.000*	Significant correlation HCT and (age, working years) together
RBC X $10^3/L$	0.975	0.000*	Significant correlation RBCs and (age, working years) together
WBCX$10^3/L$	0.950	0.000*	Significant correlation WBCS and (age, working years) together
PLTs X $10^3/L$	0.947	0.000*	Significant correlation platelets and (age, working years) together
MCV (ft)	0.984	0.000*	Significant correlation MCV and (age, working years) together
MCH (pg/cell)	0.980	0.000*	Significant correlation MCH and (age, working years) together
MCHC (%)	0.982	0.000*	Significant correlation MCHC and (age, working years) together
ALP(U/L)	0.943	0.000*	Significant correlation ALP and (age, working years) together
AST(U/L)	0.860	0.000*	Significant correlation AST and (age, working years) together
ALT(U/L)	0.934	0.000*	Significant correlation ALTand (age, working years) together
T. B (mg/dl)	0.909	0.000*	Significant correlation T. B and (age, working years) together
D. B (mg/dl)	0.845	0.000*	Significant correlation D.B and (age, working years) together

**Values represent as multiple correlation coefficients (R). (P < 0.05) was considered statistically significant*

Discussion

Radiation plays a vital role in modern medicine, serving as a powerful tool for both diagnosis and therapy. Despite these important medical benefits, radiation exposure also carries potential risks, including tissue damage and long-term health effects [3,15]. According to this knowledge, the significance of this study arises in assessing the potential impact of occupational radiation exposure on radiology department staff. The current study revealed significant differences in the hematological parameters among radiology workers chronically exposed to ionizing radiation. These include significant increases in hemoglobin (HB), mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentration (MCHC). Similar findings have been previously reported, suggesting that these changes may represent a compensatory response to radiation-induced oxidative stress [16]. Ionizing radiation generates reactive oxygen species (ROS), which can damage erythrocytes and other blood components [17].

Supporting this mechanism, a recent study demonstrated that low-dose occupational exposure among medical workers was accompanied by significant elevations in oxidative stress, indicating that this mechanism may represent an essential pathway underlying radiation-induced biological effects [18]. As a plausible response, the hematopoietic system may increase hemoglobin content within red blood cells to sustain effective oxygen transport despite subclinical cellular damage. This explanation is supported by a previous study conducted in Tripoli, Libya, which reported remarkable

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increases in MCHC and MCH among radiology workers [10]. The observed increase in Hb levels aligns with findings reported by Pakistani researchers who found elevated hemoglobin concentrations among radiology workers [6,19]. However, this result contrasts with prior studies the documented decreased Hb levels [20,21]. Interestingly, another study carried out in Egypt reported no significant changes in whole blood parameters between exposed groups [22].

Platelets are considered sensitive indicators of hematopoietic changes, and the reductions in platelet count may suggest potential effects of radiation exposure on blood cell formation. The current study reported a significant decline in platelet count, aligning with previous findings that demonstrated significant changes in platelet values among radiology personnel [10,16,23]. Nevertheless, these results are inconsistent with those of a previous study, which reported no significant changes in platelet counts, highlighting variability based on cumulative dose, protective measures, and the technical sensitivity of the laboratory assays [14]. No significant differences were revealed in WBC or lymphocyte counts in this study. In contrast, a recent study carried out in Italy (2025) demonstrated a reduced WBC count among radiation workers, suggesting potential immune modulation [12].

Equally, an animal study reported that chronic exposure to ionizing radiation induced measurable hematological alterations. However, the affected parameters were different from those detected in the current study [24]. These discrepancies may be attributed to differences in study design, sample size, radiation types, or durations of exposure.

Regarding the biochemical parameters, the reduction in direct bilirubin (D.B) observed in this study is less frequently reported in the literature. This finding may reflect subtle hepatic effects or alterations in bilirubin metabolism, and could indicate subclinical liver stress or adaptive changes in bilirubin processing due to radiation-induced oxidative damage. Although no significant differences were observed in the other hepatic parameters, a systematic review of animal studies suggested that long-term exposure to low doses of ionizing radiation could alter hepatic function and liver structure as well as induce hepatic oxidative stress and mitochondrial impairment [25]. In the same way, a recent experimental study demonstrated that chronic low-dose ionizing radiation induced alterations in biochemical parameters in mice, suggesting that such exposure may induce subtle biological effects. Nevertheless, our result is consistent with a previous study reporting no significant changes in hepatic parameters among healthcare workers exposed to chronic occupational exposure to low-dose ionizing radiation [26].

Gender-specific effects were also observed in this study. Male participants exhibited significant differences in Hb, MCH, and MCHC compared with their corresponding controls. These findings are in agreement with the earlier study that reported more evident hematological alterations among male workers [27]. Similar observations were documented in an Iranian study, which reported significant alterations in MCH and MCHC among the male exposed group, whereas no significant alterations were noticed among the female exposed group [28]. Nevertheless, exposed female workers showed more pronounced changes than exposed males, mainly in platelet counts and bilirubin levels. Similar sex differences have been previously documented, indicating that females may be more susceptible to long-term of radiation-induced cellular effects [29,30]. These differences may be attributable to hormonal influences, antioxidant capacity, DNA repair mechanisms or variations in radiation sensitivity [29]. Although no statistically significant differences were observed in other biochemical parameters in the current study, previous research reported significant alterations in liver function tests among radiology workers [19].

The lack of significant hepatic findings in the current study may indicate that the hematopoietic system is more sensitive than hepatic tissue to chronic occupational radiation exposure. The current study found no significant correlation between years of radiation exposure and the examined hematological and biochemical parameters, suggesting that duration of employment alone may not be an accurate indicator of the biological impact of radiation exposure. This finding is similar to a previous study, reporting that employment duration was not significantly associated with hematological alterations, whereas equivalent radiation dose revealed a significant relationship with alterations in RBC count [8]. In contrast, these results differ from the findings demonstrating that work experience and daily working hours were linked to hematological changes among X-ray technicians [16]. These variations may be explained by differences in radiation dose, workload, protective measures, and individual susceptibility to radiation. Overall, the differences in exposure conditions may have affected these results. Therefore, application of strict radiation safety protocols and continuous health monitoring remain essential for minimizing potential occupational health risks.

Conclusion

The study demonstrates significant alterations in specific hematological parameters among radiology workers exposed to ionizing radiation, namely increased MCH, MCHC, HB levels, and a decreased platelet count, suggesting early hematopoietic responses to chronic low-dose exposure. Conversely, no significant alterations were observed in most biochemical markers, possibly due to the lower radiosensitivity of hepatic tissues. Finally, based on these results, future studies should include larger multi-center populations to enhance statistical power and generalizability. Longitudinal designs are recommended to assess the progression or reversibility of hematological changes over time, and to evaluate the molecular Biomarkers, Including oxidative stress and DNA damage may provide indicators for plausible underlying mechanisms of radiation-induced negative effects. Further research should examine the association between cumulative exposure and hematological changes, use more sensitive methods for detecting subclinical hepatic dysfunction, and explore potential gender-related variations by assessing Female Workers Separately.

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Conflicts of Interest
The authors declare that they have no commercial or financial relationship that could be construed as a potential conflict of interest.

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