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EFFECTS OF LONG-TERM OCCUPATIONAL IONIZING RADIATION EXPOSURE ON HEMATOLOGICAL PARAMETERS OF HEALTHCARE WORKERS

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Abstract

Background:
Radiologists working in diagnostic imaging departments are routinely exposed to low levels of ionizing radiation as part of their daily professional practice. Although these exposure levels are generally within permissible limits, long-term and repeated exposure raises concerns about potential effects on hematopoiesis. Ionizing radiation can affect bone marrow function, which may lead to subtle alterations in blood cell production over time. Understanding these changes is important for ensuring the occupational health and safety of radiation-exposed healthcare workers.

Methods:
A cross-sectional observational study was conducted at Lower Dir and Swat region. A total of sixty-four healthcare professionals with over two years of radiation exposure were recruited for this study. Complete blood counts (CBC) were analyzed using the Swelab Alfa Hematology Analyzer, and the results were categorized according to duration of occupational radiation exposure: less than 5 years, 5–10 years, and more than 10 years.

Results:
Sixty-four participants were included. Overall, CBC parameters remained within normal ranges, with mean WBC 7.4 ×10⁹/L, hemoglobin 15.5 g/dL, RBC 5.1 ×10¹²/L, and platelets 287 ×10⁹/L. No significant correlation was found between duration of radiation exposure and any CBC parameter (p > 0.05). When compared across exposure groups (<5, 5–10, and >10 years), no statistically significant differences were observed. However, mild trends were noted, including slightly lower WBC, hemoglobin, and platelet counts and a modest increase in lymphocyte percentage with longer exposure duration. Overall, the changes observed were minor and not clinically significant.

Conclusion:
Even though statistically significant differences were no detected, the count of WBC, hemoglobin and platelets showed decreasing trends with increasing pattern of the occupational radiation exposure. Such results highlight the importance of periodic hematological monitoring in medical radiation professionals.

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INTRODUCTION

Health workers are exposed to different types of chemicals, biological and physical occupational risks in the hospital. One of the most significant physical occupational risks is radiation, which may induce different types of cancer (e.g. Leukemia, brain, skin and breast cancer) and other diseases in occupational radiation workers (1).

Radiation is a form of energy that moves fast as waves or particles. Radiation has two forms non-ionizing radiation (NIR) and ionizing radiation (IR). Non-ionizing radiation, low frequency electromagnetic radiation that emit energy in the form of heat and high molecular movement like ultraviolet rays, infrared rays, visible light and radio waves (2). Ionizing radiation is used excessively in the medical field for diagnostic as well as therapeutic purpose such as X-rays, Gamma rays and particles like α-particle, β-particle, protons and neutrons (3).

X-rays are electromagnetic radiations that carry high energy (100eV- 100keV) and wavelength ranges from 0.01nm to 10nm which capable to ionize atom and damage molecular bonds (4). This type of ionizing radiation can damage living tissue and produce chemically active free radicals that damage DNA (5). Different technologies such as computed tomography (CT-Scan), fluoroscopy and radiography of X-rays widely used in medical field to diagnose human diseases (6). The persistent use of diagnostic imaging increases potential risks to health workers (3).

World Health Organization's International Agency for Research on Cancer identified X-rays and Gamma rays is carcinogen (7). Soon after Roentgen's discovered X-ray in 1895, the hazardous nature of ionizing radiation was also identified. Severe skin reactions were observed in many X-ray workers. The first skin cancer caused by radiation was described in 1902. A few years later in 1911, leukemia was found in five radiation workers (8). According to International Commission on Radiological Protection (ICRP) the total dose limit for radiation workers is 100 mSv for five years and 50 mSv for one year (9).

The hematopoietic system is an extremely dynamic system that is crucial in maintaining life through the continuous production and regulation of blood cells (10). This process occurs primarily in the bone marrow of the adult, and in the adult, the hematopoietic stem cells (HSCs) are found there. These remarkable cells have the ability to both replicate themselves and mature into all the major types of blood cells: red blood cells (erythrocytes), white blood cells (leukocytes), and platelets (11). This is necessary so that the body can keep a balanced and reactive supply of blood cells which can be used to sustain everyday physiological needs and respond to body threats like infections or injuries (12,13).

The radio sensitivity of cells is different from cell to cell (14). Ionizing radiation affects human blood cells and can alter hematological profile, because the cells of hematopoietic system are highly radiosensitive. The peripheral blood count use as a marker to determine the occupational exposure (4).

The ionization radiation either damages the hematopoietic stem cells directly or impairs the capacity of cells to maintain the process of blood cells formation. Direct effects, the ionizing radiation damage the hematopoietic stem cell on the process of apoptosis, aging and cells differentiation. All these mechanisms destroy hematopoietic stem cells. Its mean that hematopoietic stem cell is more sensitive than other cell to ionizing radiation (15).

The destructive effects of ionizing radiation are either acute or chronic. Acute is an immediate response when someone is exposed to high doses of radiation for shorter durations while chronic is a long-term exposure to low doses of radiations (16). Occupational workers exposed to excessive X-ray radiation are at risk of developing life-threatening diseases often related to the hematopoietic system (6).

MATERIALS AND METHODS

This study was a cross-sectional observational study designed to assess the impact of long-term radiation exposure on blood parameters of healthcare radiation professionals. It was conducted in the Pathology and Microbiology Laboratory of the Medical Laboratory Technology Department at Riphah International University,

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Malakand Campus. A total of sixty-four blood samples were taken from radiation professionals in Dir and Swat, where they are frequently exposed to radiation as part of their daily job.

Healthcare professionals were approached at their workplace. The objective of the study was to be explained to them, and written informed consent was obtained. Radiation healthcare professionals were given a structured questionnaire to provide information about their demographic factors, work history, radiation exposure, and adherence to radiation safety measures. Two to three milliliters of whole blood was collected according to standard aseptic protocols in EDTA tubes from radiation healthcare professionals who had been working in occupational radiation for more than two years.

The blood sample of 3ml was collected aseptically and immediately transferred into an EDTA tube to prevent clotting and ensure preservation of blood cells for complete blood count (CBC) analysis. Each EDTA tube was labeled with the participant's name and ID, placed inside a labeled zip lock bag, and transported to the Pathology and Microbiology Laboratory of the Medical Laboratory Technology Department at Riphah International University, Malakand Campus for further processing.

Haematological analysis was performed using the Swelab Alfa Hematology Analyzer, which measures WBC, RBC, platelets, and indices using electrical impedance, flow cytometry, and photometry. EDTA blood samples were mixed, aspirated, and analyzed after quality control. Data were analyzed in SPSS v24, with descriptive statistics, outlier checks, and normality assessment. Exposure was grouped as 2–5, 5–10, and >10 years, and differences were evaluated using ANOVA ($p < 0.05$).

RESULTS

A total of 64 participants were enrolled in this study. Overall, the full blood count (FBC) parameters were largely within expected clinical ranges. The mean WBC, hemoglobin, and platelet counts reflected normal hematological status in most participants, with differential counts showing typical proportions of neutrophils, lymphocytes, and monocytes. However, WBC and platelet values demonstrated right-skewed distributions, indicating variability in these parameters among the study population.

Effect on WBC Count Among Exposed Groups

The mean white blood cell (WBC) count of the healthcare radiation professionals indicate a gradual decline with period of radiation exposure. The mean WBC count of participants who were less than 5 years of exposure was $6.52 \pm 1.43 \times 10^9$/L and the mean value of the participants who had 5-10 years of exposure was $6.21 \pm 1.56 \times 10^9$/L. Workers with more than 10 years of exposure had a mean count of $5.88 \pm 1.71 \times 10^9$/L. The difference among groups was not statistically significant ($p = 0.073$) though a decreasing pattern was observed with increasing exposure duration. The comparison is presented in Figure 3.1.

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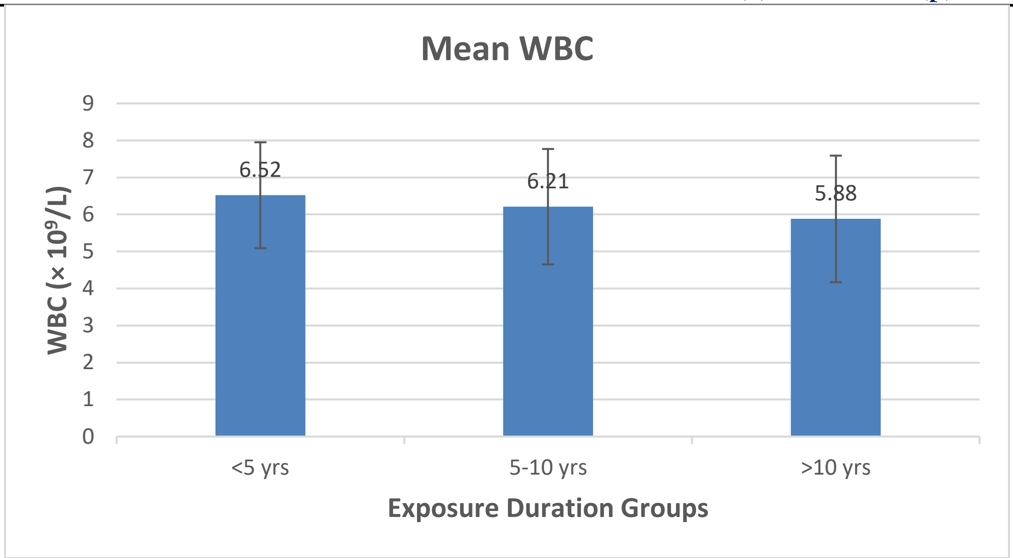

Figure 3.1: WBC's variation among the groups according to exposure duration

Assessment of RBC Count in Exposed Workers

The mean red blood cell (RBC) count of the participants who had less than 5 years of radiation exposure was 5.21 ± 0.43 $\times 10^{12}$/L, whereas participants that were exposed to radiation between 5-10 years, the mean was 5.34 ± 0.48 $\times 10^{12}$/L and The mean RBC count for participants who had been exposed for more than ten years was 5.12 ± 0.41 $\times 10^{12}$/L. No significant difference was observed between the exposure groups ($p = 0.244$). The distribution of RBC counts in the exposure categories is shown in figure 3.2.

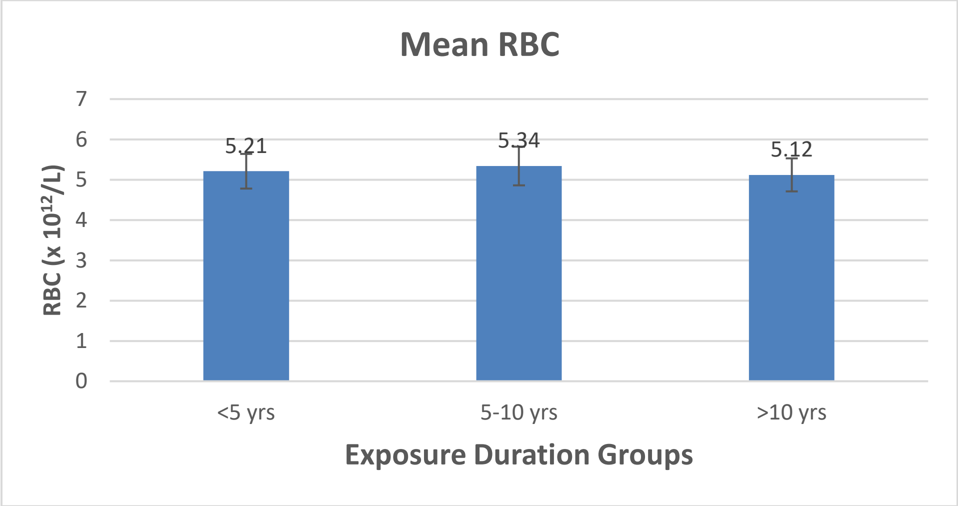

Figure 3.2: RBC's variation among the groups according to exposure duration

Hemoglobin Levels in Radiation-Exposed Healthcare Workers

The average hemoglobin (HGB) among the participants who had less than 5 years of exposure was 15.37 ± 1.14 g/dl and the mean hemoglobin of workers who had an exposure of between 5 and 10 years was 15.09 ± 1.26 g/dl. The individuals who had >10 years of exposure had a mean hemoglobin concentration of 14.82 ± 1.35 g/dL. There was a slight decreasing pattern as radiation exposure duration increased, but the difference was not found statistically

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significant ($p = 0.089$). The comparison is presented in Figure 3.3.

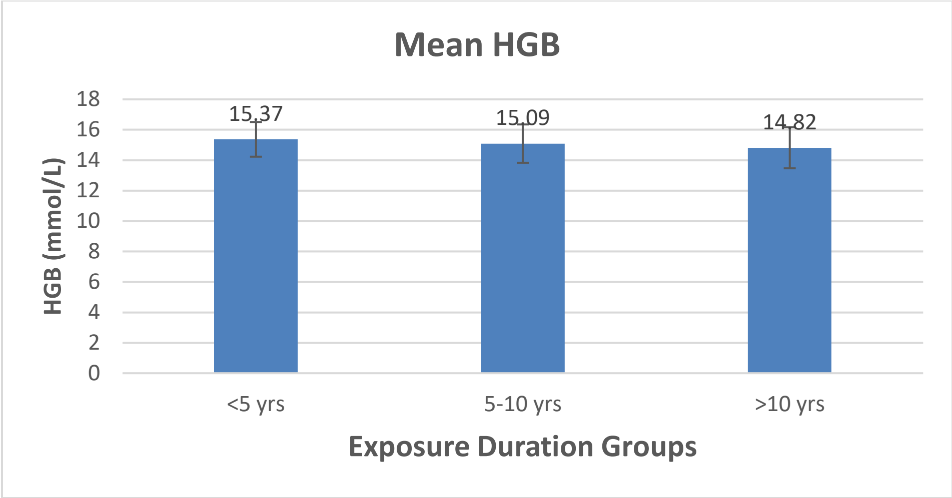

Figure 3.3: HGB variation among the exposed groups according to exposure duration

Comparison of Count of Platelets Among the Exposed Groups

Mean platelet counts in participants with the exposure of less than 5 years was 276 ± 52 $\times 10^9$/L, 258 ± 61 $\times 10^9$/L of the mean platelet counts in the participants with 5-10 years of exposure and the participants with >10 years of exposure showed a mean platelet count of 236 ± 67 $\times 10^9$/L. Even though the platelet counts showed a downward trend with longer exposure time, the variation across groups was not significant ($p = 0.064$). The comparison is illustrated in Figure 3.4.

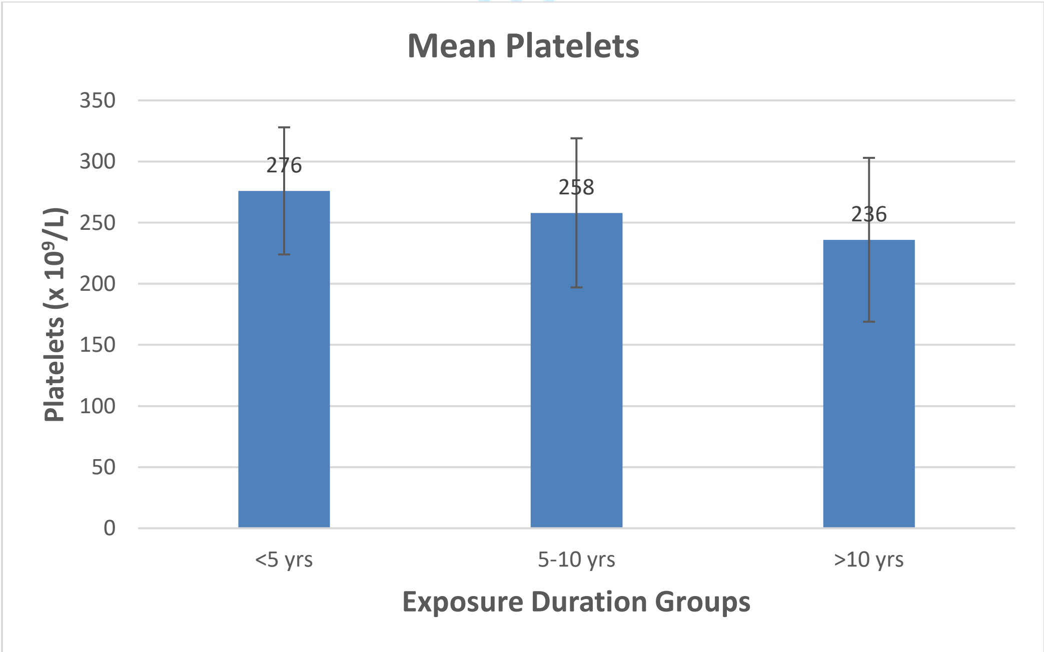

Figure 3.4: Platelet Count Variation According to Duration of Radiation Exposure Among Healthcare Workers

Lymphocyte Count Among Radiation-Exposed Workers

The average lymphocyte percentage of participants who were exposed to less than five years was 33.4 ± 6.9% and the mean of lymphocyte percentage of those who were exposed to radiation for 5-10 years was 35.7 ± 8.1%. The participants that had over 10 years of exposure revealed a mean value of 37.9 ± 9.6%With increasing duration of exposure, there was a growing tendency in the percentage of lymphocytes, but the difference between groups was not significant (p = 0.091). This comparison is presented in Figure 3.5.

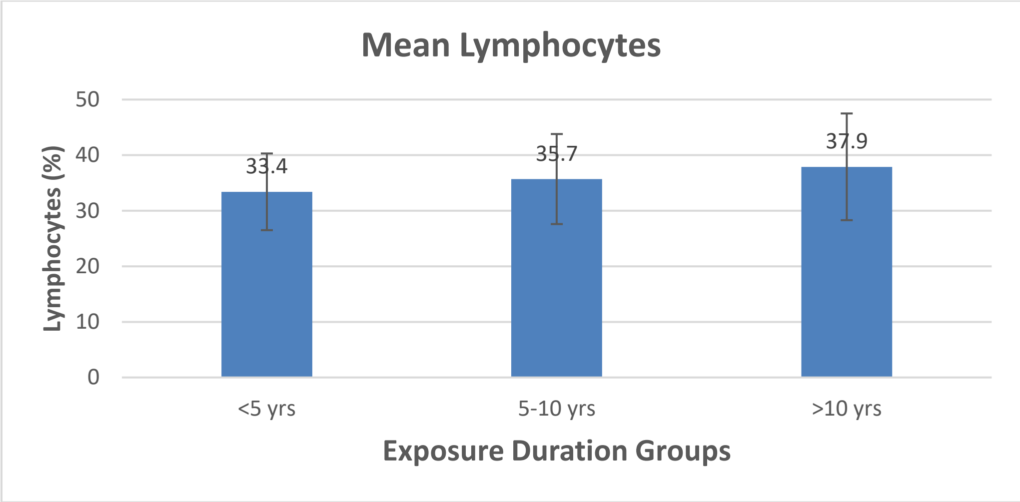

Figure 3.5: Lymphocyte variation according to radiation exposure Duration

Neutrophil Count Among Radiation-Exposed Healthcare Personnel

The mean neutrophil percentage of the participants with less than 5 years of exposure was 56.8 ± 10.2, and the participants with 5-10 years of exposure had a mean neutrophil percentage of 54.6 ± 9.4%. Employees who had more than 10 years of exposure had an average neutrophil percentage of 52.2 ± 11.1%. Though a slight reduction was noted with the increase in exposure duration, the difference was not statistically significant (p = 0.134). The distribution of neutrophil percentages is presented in Figure 3.6.

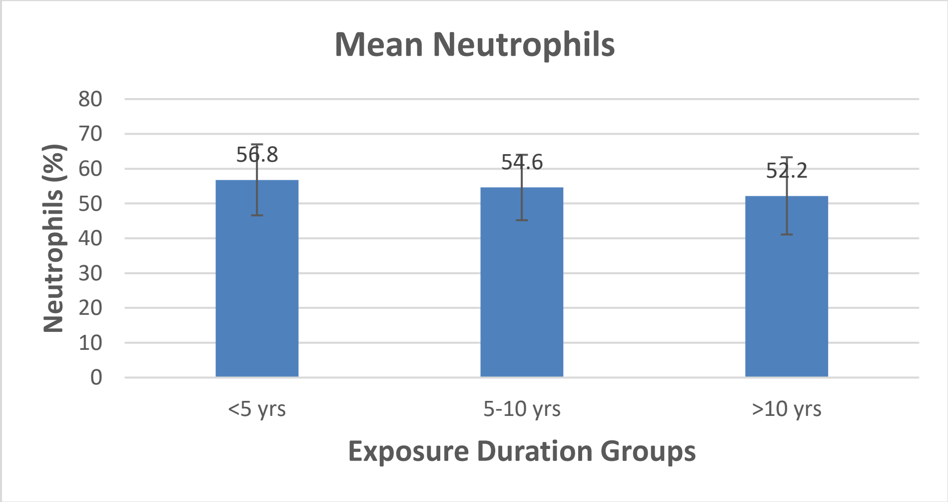

Figure 3.6: Neutrophil variation according to radiation exposure duration

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Comparison of Count of Monocytes Between Exposure Groups

The mean monocytes percentage of the participants with less than 5 years of exposure was 6.2 ± 1.6%, and the participants with 5-10 years of exposure had a mean monocytes percentage of 6.4 ± 1.8%. Monocyte percentage among the participants corresponding to more than 10 years of exposure was mean 6.5 ± 1.7%. The statistical analysis did not show a significant difference between the groups (p = 0.842). Comparisons are seen in Figure 3.7.

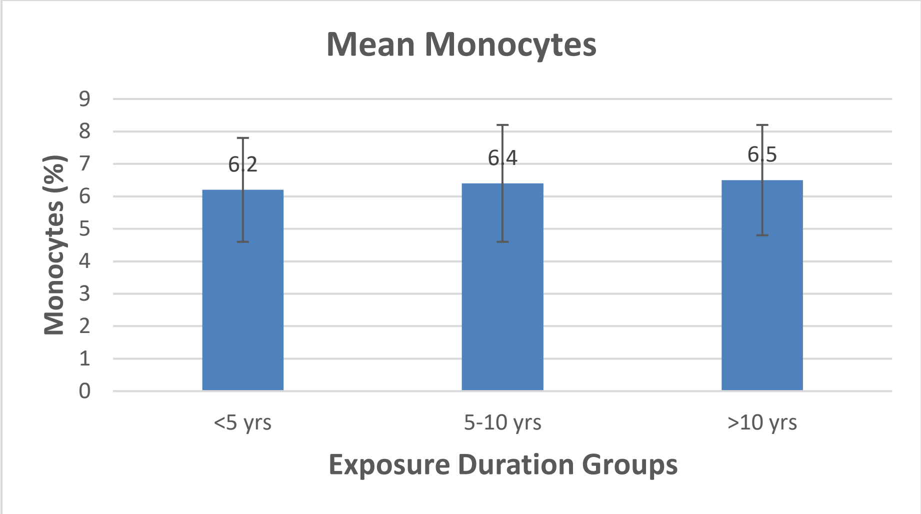

Figure 3.7: Monocyte variation by length of radiation exposure

Comparison of Count of Eosinophils Between Exposure Groups

The average eosinophil percentage of participants who were exposed to less than 5 years was 1.9 ± 0.5% and participants who were exposed to 5-9 years had a mean eosinophil percentage of 2.0 ± 0.6%. The mean value of the participants who had more than 10 years of exposure was 2.1 ± 0.6%. No statistically significant difference was found with the exposure groups (p = 0.617). The comparison is presented in Figure 3.8.

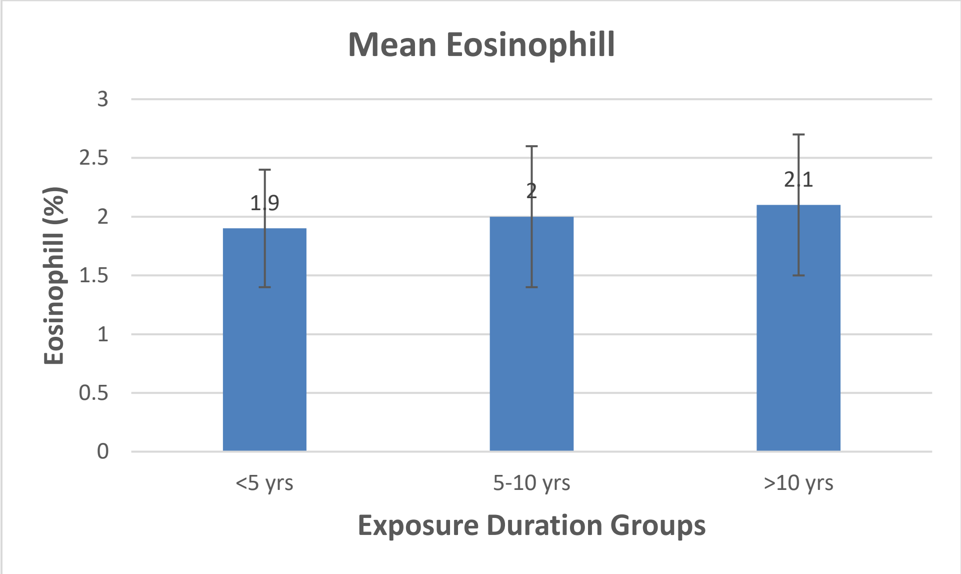

Figure 3.8: Variation in eosinophil count according to exposure duration

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Discussion

This study was designed to determine the effects of chronic radiation effects on the blood parameters of radiation workers in the healthcare sector. We paid special attention to some important parameters of CBC, such as white blood cells (WBCs), red blood cells (RBCs), platelets (PLTs) count, hemoglobin (HGB) level and the differential percentage of neutrophils, lymphocytes, monocytes and eosinophil proportion. The study involved 64 healthcare radiation professionals who were divided into three groups according to their length of exposure to radiation: less than 5 years, 5-9 years and more than 10 years of radiation exposure.

The descriptive statistics of the CBC parameters showed that the CBC parameters of all participants were within the normal clinical ranges without any extreme deviations. The average value of WBC count, hemoglobin (HGB) levels and platelet (PLT) count were 7.4 x 109/L, 15.5 g/dL, and 287 x 109/L, respectively, which are within normal healthy ranges. The neutrophil, lymphocyte, and monocyte differential counts were also within the normal clinical limits, which also indicates that overall participants did not exhibit abnormal blood profiles during the testing time.

No statistically significant correlations were found between exposure years and any of the CBC parameters when analysing the relationship between the duration of radiation exposure and blood parameters. The correlation analysis indicated weak relationships between exposure duration and most parameters, the p-values exceeding 0.05. In particular, there was no statistically significant relationship between radiation exposure and the number of WBC count ($r = 0.163$, $p = 0.197$), hemoglobin levels ($r = -0.102$, $p = 0.424$), neutrophil percentage ($r = 0.030$, $p = 0.812$), lymphocyte percentage ($r = 0.000$, $p = 1.000$), monocyte percentage ($r = -0.192$, $p = 0.129$), and platelet count ($r = -0.040$, $p = 0.755$).

Also, comparing the CBC parameters in the three exposure duration groups, there was no significant difference ($p > 0.05$) in any parameter. Although we have observed trends where the number of WBCs and platelets gradually reduced, and the percentage of lymphocytes increased with an increase in the radiation exposure duration.

We find our results consistent with a growing literature that indicates that standard CBC parameters may often not change in radiation workers under the existing safety measures (17). An example is a cohort study of Chinese medical radiation workers over five years (2015-2019) that found a decreasing trend in WBC, hemoglobin and eosinophil ratio over time, although the total number of blood cells in the populations did not differ significantly between the exposure groups at the five-year follow-up, and there was no relationship between cumulative dose and blood cell counts (18). On the same note, a cross-sectional study conducted in the radiology departments of Kurdistan showed that there were no significant differences in CBC parameters between exposed and non-exposed staff (19).

Another descriptive study that examined 95 radiology technologist which found a significant decrease in leukocyte, neutrophil and lymphocyte counts among technologists with 10-15 year exposure; however, there were no changes in RBC, hemoglobin, hematocrit and platelet counts (20). These results indicate that although long-term exposure can affect some white blood cell sub types in some situations, overall hematopoietic function (as determined by CBC) might be maintained in low dose occupational settings.

In addition, the fact that standard CBC is not very sensitive to detect small or early radiation-induced damage. One example is a systematic review of Iranian radiation workers concluded that there are very few changes in CBC parameters when exposed chronically to low doses, and that more sensitive biomarkers (chromosome aberration assays, micronucleus frequency, oxidative stress markers) are necessary to effectively detect changes (21).

In current radiology practices, the notion of effective radiation protection practices such as correct shielding, the use of personal protective equipment (PPE), dosimetry surveillance and compliance with safety measures probably ensure

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that changes in gross hematological counts are minimal or undetectable. This can be supported by recent cohort evidence where after years of exposure, the counts of peripheral blood cells were stable over the years (18) (22).

Considering the similarity of normal CBC parameters among several studies including our own and the possibility of subclinical effects noted by other recent studies employing molecular or cytogenetic techniques, it seems that CBC is not a tool enough to measure the biological effects of chronic low-dose exposure to radiation fully. Rather, CBC could be used as a screening test; a conclusive diagnosis could be given using cytogenetic tests (e.g., micronucleus test) or oxidative stress indicators, or a long-term longitudinal follow-up.

Conclusion

The study concludes that prolonged exposure to low doses of radiation can affect blood parameters of health care workers. Notably, the white blood cell (WBC) counts gradually increased, indicating the presence of low-grade chronic inflammation that was probably caused by immune cell activation brought about by cytokine. Conversely, red blood cells, hemoglobin, and platelets experienced a progressive decrease especially after 10 years of exposure. These alterations indicate that with prolonged exposure to radiation there is progressive damage in the bone marrow cells which produce blood cells.

Future recommendation

Future studies should include a larger sample size and involve participants from multiple healthcare institutions to improve the generalizability of the findings. Longitudinal research designs are suggested to estimate the long-term impacts of occupational radiation exposure on hematological parameters in the long-term. Also, other biological markers and molecular indicators of radiation exposure can be included in future research to give a more detailed picture of the possible effects of chronic, low-dose radiation exposure on the health of healthcare workers.

REFERENCES

Adliene D, Griciene B, Skovorodko K, Laurikaitiene J, Puiso J. Occupational radiation exposure of health professionals and cancer risk assessment for Lithuanian nuclear medicine workers. Environ Res [Internet]. 2020 [cited 2025 Nov 27];183:109144. Available from: https://www.sciencedirect.com/science/article/pii/S0013935120300360

Bahrami Asl F, Islami-seginsara M, Ebrahimi Kalan M, Hemmatjo R, Hesam M, Shafiei-Irannejad V. Exposure to ionizing radiations and changes in blood cells and interleukin-6 in radiation workers. Environ Sci Pollut Res. 2022 Dec 20;30(13):35757–68. doi:10.1007/s11356-022-24652-8

Shahid S, Mahmood N, Chaudhry MN, Sheikh S, Ahmad N. ASSESSMENT OF IMPACTS OF HEMATOLOGICAL PARAMETERS OF CHRONIC IONIZING RADIATION EXPOSED WORKERS IN HOSPITALS.

Mahmood SQ, Talabany BK, Hama-Soor TA. Effects of long-term X-ray exposure on CBC among radiological department staff in Sulaimani city. J Taibah Univ Med Sci. 2024 Jun;19(3):524–33. doi:10.1016/j.jtumed.2024.03.009

Mahal MH. A THESIS SUBMITTED TO THE COUNCIL OF THE COLLEGE OF SCIENCE, AL- MUTHANNA UNIVERSITY, IN PARTIAL FULFILLMENT OF REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN BIOLOGY / MICROBIOLOGY.

Musa AS, Alatta NO. EFFECTS OF LONG-TERM EXPOSURE TO LOW X-RAY ON THE BLOOD CONSISTS OF RADIOLOGY DEPARTMENT STAFF OF HEALTH CENTERS IN LIBYA.

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

Roobottom CA, Mitchell G, Morgan-Hughes G. Radiation-reduction strategies in cardiac computed tomographic angiography. Clin Radiol. 2010 Nov;65(11):859–67. doi:10.1016/j.crad.2010.04.021

Taqi AH, Faraj KA, Zaynal SA, Hameed AM, Mahmood AAA. Effects of occupational exposure of X-Ray on hematological parameters of diagnostic technicians. Radiat Phys Chem. 2018 Jun;147:45–52. doi:10.1016/j.radphyschem.2018.01.027

Ryu JK, Cho SM, Cho JH, Dong KR, Chung WK, Lee JW. Survey on low-dose medical radiation exposure in occupational workers: the effect on hematological change. Radiat Eff Defects Solids. 2013 Mar;168(3):228–46. doi:10.1080/10420150.2012.737328

Greb T. Hematopoietic Stem Cells: The Foundation of Blood Formation.

Comazzetto S, Shen B, Morrison SJ. Niches that regulate stem cells and hematopoiesis in adult bone marrow. Dev Cell. 2021 Jul;56(13):1848–60. doi:10.1016/j.devcel.2021.05.018

Orkin SH, Zon LI. Hematopoiesis: An Evolving Paradigm for Stem Cell Biology. Cell. 2008 Feb;132(4):631–44. doi:10.1016/j.cell.2008.01.025

Weissman IL. Stem cells: units of development, units of regeneration, and units in evolution. cell. 2000;100(1):157–68.

Heidari S, Taheri M, Pouyandeh Ravan A, Moghimbeigi A, Mojiri M, Naderi-Khojastehfar Y, et al. Assessment of some Immunological and Hematological Factors among Radiation Workers. J Biol Todays World. 2016;5(7). doi:10.15412/J.JBTW.01050702

Surniyantoro HNE, Rahardjo T, Lusiyanti Y, Rahajeng N, Sadewa AH, Hastuti P, et al. Assessment of Ionizing Radiation Effects on the Hematological Parameters of Radiation-Exposed Workers. At Indones. 2019 Aug 14;45(2):123. doi:10.17146/aij.2019.916

Hamzah J Joudoh, Ammani Jassim Mohammed, Kadhim NF. Effects of External Radiation Exposure on some Hematological Parameters of Hospitals Workers Staff [Internet]. Unpublished; 2018 [cited 2025 Jan 16]. Available from: http://rgdoi.net/10.13140/RG.2.2.35963.77600 doi:10.13140/RG.2.2.35963.77600

Smith T, Quencer K, Smith T, Agrawal D. Radiation Effects and Protection for Technologists and Other Health Care Professionals. Radiol Technol [Internet]. 2021 [cited 2025 Nov 27];92(5). Available from: https://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=00338397&AN=149810108&h=t5hlVT37kal95n4Zbat42KQHH3l%2B04oVjonpeg9zTaFUaumlRsR6fwdBUzr3XNVdU0D6TgkVBpKjVtlLFsLfhQ%3D%3D&crl=c

Wang G, Xu C, Li S, Zhang D, Chen Y, Liu J, et al. THE INFLUENCE OF LOW-DOSE OCCUPATIONAL RADIATION EXPOSURE ON PERIPHERAL BLOOD CELLS IN A COHORT OF CHINESE MEDICAL RADIATION WORKERS. Radiat Prot Dosimetry. 2022 Mar 1;198(4):246–56. doi:10.1093/rpd/ncac033

Mahmood SQ, Talabany BK, Hama-Soor TA. Effects of long-term X-ray exposure on CBC among radiological department staff in Sulaimani city. J Taibah Univ Med Sci. 2024 Mar 28;19(3):524–33. doi:10.1016/j.jtumed.2024.03.009 PubMed PMID: 38590508; PubMed Central PMCID: PMC11000182.

Waggiallah DH. The Effect of X-Ray Radiationon Hematopoietic Tissue Among Radiology Technologists: The Effect of X-Ray Radiationon Hematopoietic Tissue Among Radiology Technologists. Natl J Integr Res Med. 2013 Apr 30;4(2):16–20. doi:10.70284/njirm.v4i2.2140

ISSN: (e) 3007-1607 (p) 3007-1593

ZARE A, MORTAZAVI SMJ. The Efficacy of Periodic Complete Blood Count Tests in Evaluation of the Health Status of Radiation Workers in Iran: A Systematic Review. Iran J Public Health. 2020 Apr;49(4):628–36. PubMed PMID: 32548042; PubMed Central PMCID: PMC7283191.Miller DL, Vañó E, Bartal G, Balter S, Dixon R, Padovani R, et al. Occupational Radiation Protection in Interventional Radiology: A Joint Guideline of the Cardiovascular and Interventional Radiology Society of Europe and the Society of Interventional Radiology. Cardiovasc Intervent Radiol. 2010 Apr;33(2):230–9. doi:10.1007/s00270-009-9756-7 PubMed PMID: 20020300; PubMed Central PMCID: PMC2841268.