Effects of Low-Dose X-Ray Exposure on Hematological Parameters *In Vivo*

Venu Anand Das Vaishnav [1*], Syed Sabir Ali [1]

Abstract

Background: High levels of IR are known to induce cancer and disrupt biological processes through oxidative damage primarily driven by reactive oxygen species (ROS) overproduction. This study aims to investigate the effects of low-dose X-ray exposure on Hematologic parameters in Wistar albino rats, contributing to the limited literature on low-dose X-ray exposure and its impacts on health. Methods: Adult male Wistar albino rats, averaging 150 ± 25 g, were divided into four experimental groups. The rats underwent irradiation using a 6 MV linear accelerator, and blood samples were collected for biochemical analysis. Hematologic parameters, including Red Blood Cells (RBCs), platelets (PLTs), hemoglobin (Hb), white blood cells (WBCs), lymphocytes (LY), and granulocytes (GRAN), were assessed. Results: Significant variations in hematologic parameters were observed based on the method and dosage of radiation. The RBC count decreased from 9.15 ± 0.21 (control) to 3.32 ± 0.25 (higher dosage), a reduction of 58.93%. Platelet counts dropped by 51.43% and 32.46% for single and fragmented dosage approaches, respectively. Moreover, WBC and granulocyte counts were significantly reduced, with hemoglobin levels declining by 47.52% and 57.34% following specific irradiation rates ($p < 0.001$).

Conclusion: The findings underscore the adverse effects of ionizing radiation on hematologic parameters, indicating that low-dose X-ray exposure does not promote an adaptive response in hematology when followed by higher radiation doses.

Keywords: Ionizing Radiation, Reactive Oxygen Species, Adaptive Response, Hematological Parameters

Significance | This study determined the risks of low-dose X-ray exposure on blood parameters, contributing to radiation safety knowledge.

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Editor Surendar Aravindhan, Ph.D., And accepted by the Editorial Board Sep 09, 2024 (received for review Jul 12, 2024)

Introduction

Exposure to ionizing radiation (IR), particularly X-ray radiation, poses significant health risks, especially concerning hematologic parameters. Ionizing radiation can induce a range of biological effects, primarily through oxidative stress mechanisms, which result from the overproduction of reactive oxygen species (ROS) within cells (Tong & Hei, 2020). This oxidative stress can lead to damage in cellular structures, including those in the blood, manifesting as alterations in hematologic parameters such as red blood cells (RBCs), white blood cells (WBCs), and platelets (PLTs). While high doses of radiation, such as those utilized in computed tomography (CT), are well-documented to adversely affect hematological health and increase cancer risk, there is limited research on the impact of low-dose radiation exposure (Tolonen et al., 2021). Importantly, hematologic parameters serve as critical indicators of systemic health and can reflect the body's response to radiation exposure. As radiation exposure increases, changes in blood composition can signify a compromised immune system, impaired oxygen transport, and potential for increased infection risk (Murphy et al., 2022). Understanding the nuances of how different radiation doses influence hematological parameters is essential for assessing the overall health impacts of ionizing radiation in both clinical and environmental contexts.

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Please cite this article.
Venu Anand Das Vaishnav, Syed Sabir Ali (2024). Effects of Low-Dose X-Ray Exposure on Hematological Parameters In Vivo, Journal of Angiotherapy, 8(9), 1-5, 9879

The effects of ionizing radiation on hematologic parameters are multifaceted and can lead to significant health implications. Studies have consistently demonstrated that exposure to IR results in pronounced alterations in blood cell counts, particularly in RBCs, WBCs, and PLTs. For instance, high radiation doses have been associated with significant decreases in RBC counts, indicative of impaired erythropoiesis and potential anemia (Murphy et al., 2022). The reduction in WBC counts further signifies compromised immune function, rendering individuals more susceptible to infections and diseases.

Interestingly, the concept of radiation-induced adaptive response (RIAR) has emerged as a potential mechanism for understanding the body's resilience to radiation (Sisakht et al., 2020). RIAR posits that initial exposure to a low dose of radiation can prime cellular mechanisms that protect against subsequent higher doses. However, the evidence supporting RIAR is not universally observed, with studies reporting varying outcomes based on the biological context and radiation exposure conditions (Jepeal et al., 2021). For example, some studies have shown that low-dose radiation does not elicit a protective adaptive response in hematologic parameters, suggesting that the protective mechanisms may differ across tissue types and exposure levels (Sia et al., 2020).

Furthermore, the oxidative damage resulting from excessive ROS production in response to ionizing radiation can overwhelm the body's antioxidant defenses, leading to significant cellular and structural damage (Tong & Hei, 2020). This imbalance can precipitate a cascade of biological responses, including inflammation and apoptosis, which may exacerbate the decline in hematologic health. The intricate interplay between radiation exposure, oxidative stress, and hematologic outcomes necessitates further investigation to elucidate the underlying mechanisms and to develop effective strategies to mitigate these adverse effects.

Understanding the impacts of ionizing radiation on hematologic parameters is critical for evaluating health risks associated with both medical and environmental radiation exposure. Future research should focus on delineating the dose-response relationships and the potential for adaptive responses across various biological models to inform clinical practices and public health policies.

2. Materials and Methods

2.1 Animals

The study employed adult male Wistar albino rats with an average weight of 150 ± 25 g. All experimental procedures adhered to ethical guidelines approved by the Institutional Animal Care and Use Committee (IACUC), ensuring minimal suffering and humane treatment. Animal welfare considerations were prioritized throughout the study, adhering to the 3Rs principle (Replacement, Reduction, Refinement) to minimize animal use and enhance study quality.

The rats were housed in a controlled environment with a temperature range of 20–25°C and a 12-hour light/dark cycle. Standard laboratory chow and water were provided ad libitum. The rats were randomly assigned to four experimental groups, each consisting of five animals. The first group, the Sham-Irradiated Group, included rats that were not exposed to radiation but were handled similarly to the irradiated groups to account for any stress caused by handling. The second group, known as the 2 Gy Group, consisted of rats exposed to total body irradiation of 2 Gy at a dosage rate of 4 Gy/min. These rats were euthanized 24 hours after radiation exposure. The third group, referred to as the 10 cGy Group, received whole-body irradiation of 10 cGy at a dosage rate of 4 Gy/min, and euthanasia was performed 48 hours post-exposure. Finally, the Primed Group included rats that were given a priming dose of 10 cGy X-rays, followed by a challenging dose of 2 Gy X-rays 24 hours later. These rats were euthanized 24 hours after the challenging dose.

2.2 Irradiation Procedure

X-ray irradiation was conducted using 6 MV linear accelerators. To minimize stress and movement, rats were anesthetized with halothane before positioning. The rats were placed in a supine position (chest facing upwards) at the center of the irradiation field to ensure uniform dose distribution and avoid exposure to the penumbra region, which is characterized by non-uniform radiation doses.

2.3 Sample Collection

Following the experimental protocol, all rats were administered halothane anesthesia for humane euthanasia. Blood samples were collected via cardiac puncture using heparinized syringes for biochemical analysis. The blood samples were centrifuged at 550 g for 5 minutes to separate the plasma, which was stored at -85°C until analysis.

2.4 Biochemical Investigations

Biochemical analyses included assessments of Red Blood Cells (RBCs), platelets (PLTs), hemoglobin (Hb), white blood cells (WBCs), lymphocytes (LY), and granulocytes (GRAN). Blood samples were sent to a certified diagnostic center for evaluation. All procedures followed laboratory standards to ensure accuracy and reliability of the results.

2.5 Statistical Analysis

Data were expressed as mean ± Standard Deviation (SD). Comparisons between groups were performed using two-tailed t-tests, with significance thresholds set at $p < 0.05$, $p < 0.005$, and $p < 0.001$. Statistical analyses were conducted using GraphPad Prism 6.0 software for Windows. All results were interpreted within the context of the study objectives, emphasizing statistically significant findings in the context of radiation exposure.

Table 1. X-ray Exposure Analysis in Wistar Albino Rats. This table presents the hematologic parameters of adult male Wistar albino rats subjected to varying levels of X-ray exposure. The parameters measured include Red Blood Cells (RBC), Platelets (PLT), White Blood Cells (WBC), Granulocytes (GRAN), Hemoglobin (Hb), and Lymphocytes (LY). Data show significant reductions in RBC counts and other hematologic values across different exposure groups, indicating the adverse effects of ionizing radiation.

SN	RBC	PLT	WBC	GRAN	Hb	LY
1	7.98	863.88	14.21	52.34	19.32	41.23
2	6.12	482.65	6.47	34.23	11.32	21.24
3	3.63	402.69	4.15	24.32	9.42	16.32
4	6.21	693.54	6.49	38.42	13.24	24.32
5	5.15	513.07	6.67	35.42	11.53	23.12

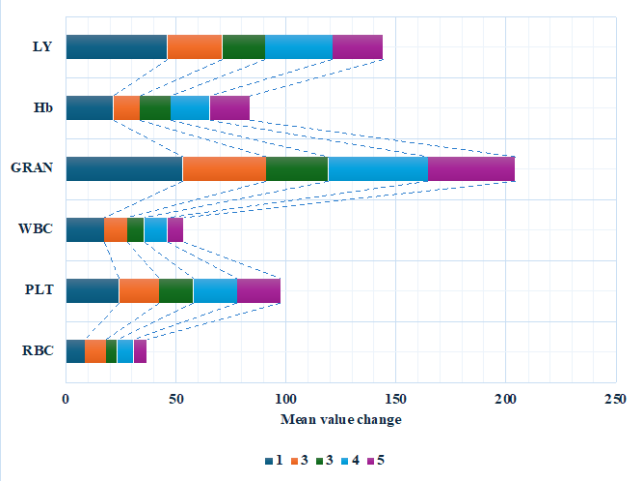

Figure 1. Mean Value Change Analysis of Hematologic Parameters in Wistar Albino Rats. This figure illustrates the mean changes in hematologic parameters (RBC, PLT, WBC, GRAN, Hb, and LY) in Wistar albino rats following X-ray exposure. The data highlight significant decreases in these parameters, particularly in the groups exposed to higher radiation doses, reflecting the detrimental impact of ionizing radiation on blood components.

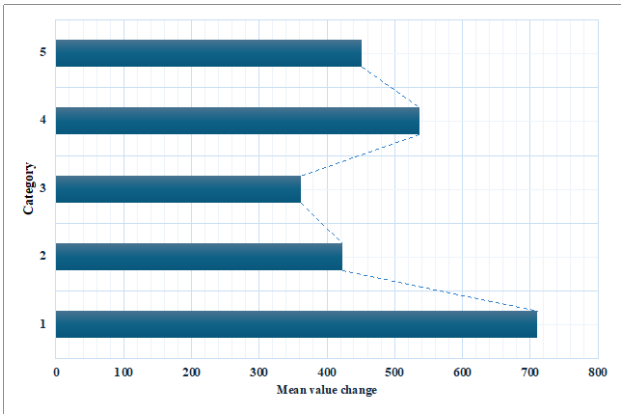

Figure 2. Mean Value Change of Biochemical Parameters in Wistar Albino Rats. This figure depicts the mean value changes in biochemical parameters, focusing on hematology function indicators, following X-ray exposure in Wistar albino rats. The analysis indicates significant lipid peroxidation and protein carbonylation, with no evidence of an adaptive response in blood tissues, underscoring the harmful effects of ionizing radiation.

3. Results and Discussion

The analysis of the whole blood counts in rats revealed significant variations based on the radiation exposure method, including the type of dosage—whether segmented or single—and the rate of dosage applied (Table 1). Notably, the results indicated substantial differences in hematologic parameters, such as Red Blood Cells (RBCs), platelets (PLTs), hemoglobin (Hb), white blood cells (WBCs), lymphocytes (LY), and granulocytes (GRAN). The control group exhibited an RBC count of 9.15 ± 0.21, whereas the groups exposed to lower and higher dosage rates after a single dosage of 18 Gy showed counts of 6.12 ± 0.23 and 3.32 ± 0.25, respectively. The significant decrease of 58.93% in RBC count in rats subjected to a single dosage of 2400M/min radioactivity underscores the detrimental impact of high radiation doses on erythropoiesis.

Platelet counts similarly demonstrated a notable decline, with decreases of 51.43% and 32.46% for single and fragmented dosage approaches at higher frequency radiation, respectively. Conversely, the PLT values for lower dosage rates showed declines of 41.34% and 37.83%. Furthermore, the exposure to radiation significantly reduced WBC and granulocyte counts. The variation in these parameters appears to correlate with the dosage rates and fractionation schedules of the irradiation ($p < 0.001$). Hemoglobin levels decreased markedly by 47.52% and 57.34% following single fraction injections at 650 and 2500 MU/min, respectively, compared to the control category.

Figure 1 illustrates the distribution of RBCs, WBCs, granulocytes, hemoglobin, and lymphocytes across the different experimental categories, while Figure 2 highlights the alterations in PLT counts among the various groups. The significant reductions in these hematological parameters point to the adverse effects of ionizing radiation, which is well-documented in the literature (Tong & Hei, 2020; Silver et al., 2021).

Overall, this study emphasizes the need for a nuanced understanding of the effects of radiation on hematologic parameters. Further research is warranted to elucidate the underlying mechanisms of radiation-induced changes and the potential for therapeutic interventions to mitigate these effects.

4. Conclusion

In conclusion, this study highlighted the detrimental effects of ionizing radiation on hematologic parameters in Wistar albino rats. Significant reductions in red blood cells (RBCs), white blood cells (WBCs), platelets (PLTs), and hemoglobin levels were observed, correlating with increased radiation exposure. These findings underscore the risks associated with both high and low doses of radiation, particularly concerning the compromised immune function and potential for anemia. The absence of an adaptive response to the priming dose of 10 c-Gy prior to a higher dose indicates that low-level exposure may still invoke harmful biological effects. This reinforces the necessity for further research to explore the mechanisms behind these radiation-induced changes and their implications for health, particularly in clinical and environmental settings. Understanding these dynamics is crucial for developing effective strategies to mitigate the adverse impacts of ionizing radiation on public health.

Author contributions

VADV and SSA contributed to conceptualization, fieldwork, data analysis, drafting the original manuscript, editing, funding acquisition, and manuscript review. Both VADV and SSA were involved in research design, methodology validation, data analysis, visualization, and manuscript review and editing. Additionally, VADV took the lead in methodology validation, investigation, funding acquisition, supervision, and final revisions. All authors have reviewed and approved the final version of the manuscript.

Acknowledgment

The authors were grateful to their department.

Competing financial interests

The authors have no conflict of interest.

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