

A Study on Chromosomal Aberrations in Peripheral Blood Immune Cells of Medical Radiation Diagnostics Practitioners Exposed to Occupational Radiation

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ABSTRACT

Objective: To investigate the health effects of radiation exposure among medical radiation diagnostics practitioners. **Methods:** A total of 1125 medical radiation diagnostics workers who underwent occupational health examinations between 2023 and 2024 were selected as the study subjects. They were categorized into groups based on gender, age, and length of service. Differences in white blood cell count, platelet count, and chromosomal aberration rates among the groups were analyzed. Logistic regression was used to identify factors influencing the rate of chromosomal aberrations. **Results:** Among the 1125 workers, 684 (60.8%) were male and 441 (39.2%) were female. The non-aberration group comprised 1060 individuals (94.2%), with a mean radiation exposure duration of 6.85 ± 8.137 years and a mean age of (33.17 ± 10.420) years. The chromosomal aberration group included 65 individuals (5.8%). Radiation exposure time and age were identified as influencing factors for chromosomal aberrations in radiation workers ($P < 0.05$). For each additional year of radiation exposure, the risk of chromosomal aberrations increased by 3.9% (OR = 1.039, 95% C.I. 1.013-1.067). **Conclusion:** Long-term, low-dose ionizing radiation exposure leads to an increased incidence of chromosomal aberrations. Enhanced monitoring and improved radiation protection for medical radiation practitioners are recommended.

KEYWORDS

Radiation Workers; Low-Dose Ionizing Radiation; Chromosomal Aberrations; Health Surveillance

1. INTRODUCTION

Medical radiation diagnostics practitioners may sustain damage to tissues and organs such as the hematopoietic system, thyroid, and ocular lens due to prolonged exposure to low-dose ionizing radiation [1-3]. Consequently, regular occupational medical examinations (OME) are essential for safeguarding the health of radiation workers. The types of radiation exposure vary among radiology department personnel. In X-ray, CT, and digital subtraction angiography (DSA) procedures, healthcare workers are exposed to X-rays; in nuclear medicine, gamma rays are encountered during the preparation of radiopharmaceuticals; while beta particles are involved during isotope production and nuclear waste handling [4, 5]. This study selected 1,125 radiation workers from a tertiary hospital in Guangdong Province, China, between January 2023 and December 2024 to investigate the impact of long-term low-dose ionizing radiation exposure on chromosomal aberrations in peripheral blood immune cells among medical radiation diagnostics practitioners, thereby providing evidence for enhancing occupational health surveillance.

2. METHODS

2.1. Study Subjects

The study enrolled 1,125 medical radiation diagnostics workers who underwent occupational health examinations at a tertiary hospital in Guangdong Province, China, between January 1, 2023, and December 31, 2024. Data collected included age, gender, job category, duration of radiation exposure, and white blood cell count.

2.2. Methods

2.2.1. Chromosomal aberration analysis of peripheral blood lymphocytes

A 0.5 mL venous blood sample was collected from each medical radiation diagnostics worker and added to 5 mL of RPMI-1640 culture medium. The cultures were treated with colchicine at a concentration of 0.04 $\mu\text{g/mL}$ and incubated in a constant temperature incubator at $(37.0 \pm 0.5)^\circ\text{C}$ for 52 hours. After hypotonic treatment and fixation, specimens were prepared. The GSL120 automatic chromosome scanning system (Leica, Germany) was used for image acquisition. For each sample, 100 to 150 metaphase spreads were selected, and aberration types were counted and recorded using the CytoVision software system. Results were evaluated in accordance with the Chinese national standard GBZ248-2014 Criteria for Chromosomal Aberration Analysis in Peripheral Blood Lymphocytes of Radiation Workers for Occupational Health Examination [6], with verification by two independent technicians. The criteria for a positive chromosomal aberration were defined as a dicentric chromosome (dic) plus centric ring (r) aberration rate exceeding 1%, or an acentric fragment (ace) aberration rate exceeding 3%.

2.2.2. Routine blood tests

A 2 mL fasting venous blood sample was collected from each participant. Quantitative analysis of blood cell components was performed using the Mindray BC-6800 hematology analyzer. The established reference ranges were as follows: white blood cell count $(4.0\text{--}9.5) \times 10^9/\text{L}$, platelet count $(100\text{--}350) \times 10^9/\text{L}$, and absolute lymphocyte count $(1.1\text{--}3.2) \times 10^9/\text{L}$.

2.3. Statistical Analysis

Data were analyzed using SPSS Statistics version 23.0. Continuous variables, including age, white blood cell count, platelet count, and duration of radiation exposure, are presented as mean \pm standard deviation ($\bar{x} \pm s$). Categorical variables such as gender were summarized using frequencies and percentages. Differences in the prevalence of abnormal examination indicators across groups were compared using the chi-square test. Factors influencing occupational health examination outcomes in radiation workers were assessed via multivariate logistic regression analysis. A p-value of less than 0.05 was considered statistically significant.

3. RESULTS

3.1. Baseline Characteristics of the Two Groups

This study included 1,125 radiation workers, comprising 684 males (60.8%) and 441 females (39.2%). The non-aberration group consisted of 1,060 individuals (94.2%), with a mean radiation exposure duration of 6.85 ± 8.137 years and a mean age of 33.17 ± 10.420 years. The chromosomal aberration group included 65 individuals (5.8%), with a mean age of 37.97 ± 13.627 years and a mean radiation exposure duration of 10.43 ± 10.322 years. The overall mean exposure duration across all participants was 9.47 ± 7.16 years.

Table 1. Comparison of baseline characteristics between the two groups

Variables	Non-aberration group (n=1060)	Aberration group (n=65)	t/ χ^2	P
Age	33.17±10.420	37.97±13.627	-2.787	0.007
Gender			2.877	0.090
Male	638	46		
Female	422	19		
Radiation exposure duration (years)	6.85±8.137	10.43±10.322	-2.747	0.008
White blood cell count	(5.95±1.467)×10 ⁹ /L	(5.99±1.611)×10 ⁹ /L	-0.174	0.862
Platelet count	(261.47±54.417)×10 ⁹ /L	(256.68±51.192)×10 ⁹ /L	0.691	0.691
Absolute lymphocyte count	(1.94±0.501)×10 ⁹ /L	(1.96±0.553)×10 ⁹ /L	-0.328	0.743

3.2. Preparation and Aberration Analysis of Peripheral Blood Lymphocyte Chromosome Specimens

Following the preparation and aberration analysis of peripheral blood lymphocyte chromosome specimens, representative chromosomal aberration types are illustrated in Figure 1, including normal chromosomes without aberrations, dicentric chromosomes, trivalent chromosomes, and ring chromosomes.

A dicentric chromosome is formed when two chromosomes each undergo a single break, and the resulting segments containing the centromeres join at the break sites, creating a new chromosome with two centromeres. A centric ring chromosome typically results from two breaks in a single chromosome, after which the segment containing the centromere rejoins at both ends to form a ring structure. Acentric fragments, lacking a centromere, are usually lost during cell division [7].

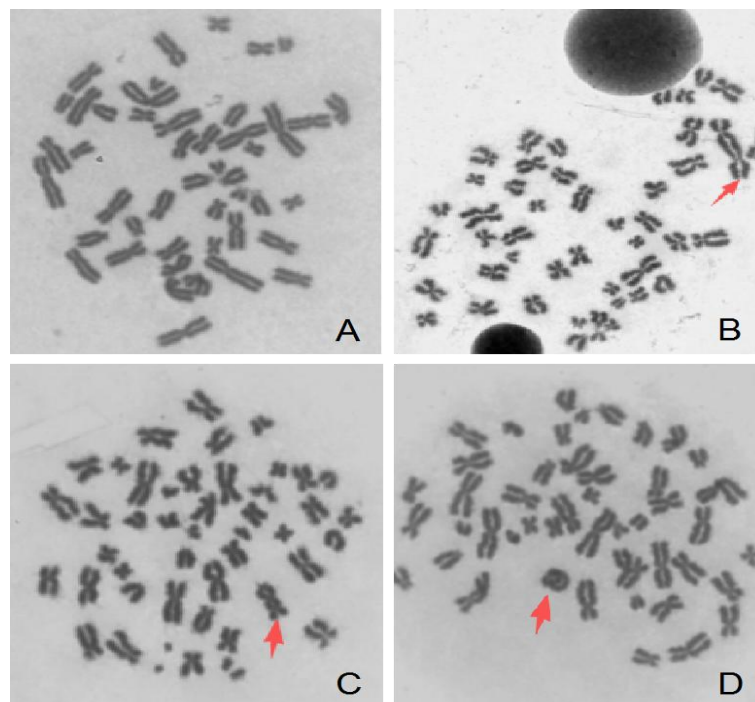


Figure 1. Chromosomal aberrations in lymphocytes

(A: normal chromosome; B: dicentric chromosome; C: trivalent chromosome; D: ring chromosome)

3.3. Univariate Analysis of Factors Influencing Lymphocyte Chromosomal Aberrations in Radiation Workers

Using chromosomal aberration as the dependent variable and gender, duration of radiation exposure, white blood cell count, platelet count, and absolute lymphocyte count as independent variables, logistic regression analysis was performed. The results indicated that duration of radiation exposure and age were significant influencing factors for chromosomal aberrations in radiation workers ($P < 0.05$), while gender, white blood cell count, platelet count, and absolute lymphocyte count showed no statistically significant effects on the rate of chromosomal aberrations, as detailed in Table 2.

Table 2. Univariate logistic regression analysis

Variables	β	OR	95% C.I.	P-value
Age	0.035	1.036	1.015-1.056	0.001
Gender	-0.471		0.361-1.081	0.092
Male		1		
Female		0.624		
Radiation exposure duration (years)	0.042	1.043	1.017-1.070	0.001
White blood cell count	0.015	1.015	0.858-1.201	0.862
Platelet count	-0.002	0.998	0.994-1.003	0.489
Absolute lymphocyte count	0.082	1.086	0.665-1.773	0.743

3.4. Multivariate Analysis of Factors Influencing Lymphocyte Chromosomal Aberrations in Radiation Workers

To further investigate the relationship between chromosomal aberrations and duration of radiation exposure, a multivariate logistic regression analysis was performed adjusting for potential confounding factors including gender, white blood cell count, platelet count, and absolute lymphocyte count. The analysis revealed that each additional year of radiation exposure among medical radiation diagnostics practitioners was associated with a 3.9% increase in the risk of chromosomal aberrations (OR = 1.039, 95% CI: 1.013-1.067).

Table 3. Multivariate logistic regression analysis

Variables	β	OR	95% C.I.	P-value
Radiation exposure duration (years)	0.039	1.039	1.013-1.067	0.003

4. DISCUSSION

Due to the demands of their work environment, medical radiation diagnostics practitioners are inevitably exposed to radiation. Long-term, low-dose ionizing radiation exposure can induce transient symptoms such as fatigue, nausea, dizziness, headache, weakness, memory decline, and leukopenia [8]. Hematopoietic cells are highly sensitive to ionizing radiation, and alterations in white blood cell count serve as an early indicator of radiation-induced damage. The effects and symptoms of ionizing radiation on the human body are primarily associated with radiation dose and duration of exposure, with common manifestations including short-term acute injuries (e.g., skin erythema, vomiting) and long-term health risks (e.g., cancer) [9]. Prolonged radiation exposure may also induce lens opacity and thyroid dysfunction, leading to conditions such as lens opacification and hypothyroidism [10]. As a sensitive biological indicator of ionizing radiation, chromosomal aberrations in peripheral blood lymphocytes have been incorporated into the Chinese national standard GBZ98-2020 "Health Requirements and Surveillance Standards for Radiation Workers" as a mandatory test for pre-employment and post-employment examinations. This method is widely applied in biological dosimetry for low-dose ionizing radiation [6].

Chromosomal aberrations primarily manifest as DNA double-strand breaks. Ionizing radiation carries substantial energy capable of ionizing atoms and molecules, such as water molecules. DNA double-strand breaks can result either directly from the disruption of chemical bonds by radiative energy or indirectly through the radiolysis of water molecules. Upon radiolysis, water molecules form free radicals due to electron deficiency, generating species such as $\cdot\text{OH}$ and $\cdot\text{H}$. These radicals can attack DNA bases and sugar moieties, leading to double-strand breaks. Following breakage, DNA initiates spontaneous repair primarily through either non-homologous end joining (NHEJ) or homologous recombination (HR). The NHEJ repair mechanism often results in base pair deletions or insertions, thereby contributing to chromosomal aberrations.

The hematopoietic system is one of the primary target organs of ionizing radiation damage. Prolonged exposure to low-dose radiation environments can readily impair hematopoietic function, manifesting as reductions in various blood cell counts in peripheral blood tests [11]. Firstly, long-term low-dose radiation exposure leads to cumulative DNA damage, increasing the probability of chromosomal aberration formation (dicentric chromosomes, centric rings, and fragments). Secondly, the DNA repair capacity (including homologous recombination and non-homologous end joining) of hematopoietic stem cells and lymphocytes declines in middle-aged and older adults, making them more susceptible to accumulation of radiation-induced damage. A study by the Hunan Provincial Institute of Occupational Disease Prevention and Control demonstrated that the chromosomal aberration rate in interventional radiology workers with over 30 years of radiation exposure (18.18%) was significantly higher than in those with ≤ 10 years of exposure (1.23%) [12].

Chromosomal aberrations in lymphocytes represent the “gold standard” for assessing radiation damage. This study employed logistic regression analysis to explore influencing factors of chromosomal aberrations, revealing that the duration of radiation exposure is a risk factor for increased aberration rates among medical radiation diagnostics practitioners. Multivariate logistic regression analysis demonstrated that each additional year of occupational exposure was associated with a 3.9% elevation in the risk of chromosomal aberrations (OR = 1.039, 95% CI: 1.013-1.067). This finding aligns with research by Fu Q et al. [13], though our study specifically focuses on medical radiation diagnostics practitioners as the study population.

In summary, long-term low-dose radiation exposure elevates the rate of chromosomal aberrations among medical radiation diagnostics practitioners, with increased duration of exposure identified as a significant risk factor. These findings underscore the need for administrative authorities to strengthen occupational health monitoring systems, enhance radiation protection measures, promote the customization and intelligent upgrading of protective equipment, and advance the adoption of remote automated operation technologies. Workers with prolonged radiation exposure represent a key priority group for occupational health surveillance. It is imperative to optimize protective strategies for senior staff—such as shortening monitoring intervals and reinforcing antioxidant interventions—to mitigate long-term occupational risks.

REFERENCES

- [1] Lusiyanti Y, Tetriana D, Suvifan VA, Kisnanto T, Yusuf D, Budiantari CT, Sumiyantoro HNE, Basri IKH, Purnami S. Preliminary Study of Spontaneous Micronuclei and Hematology Profile of Workers Exposed to Low-Dose Radiation. *Asian Pac J Cancer Prev*. 2025 Mar 1; 26(3):1035-1041. doi: 10.31557/APJCP.2025.26.3.1035. PMID: 40156422; PMCID: PMC12174547.
- [2] RICHARDSON D B, LEURAUD K, LAURIER D, et al. Cancer mortality after low dose exposure to ionising radiation in workers in France, the United Kingdom, and the United States (INWORKS): cohort study [J]. *BMJ* (Online), 2023, 382: e74520.
- [3] Bian YF, Zhong HC, Jin Q, Pan PP. [Analysis of cytogenetic indexes and occupational characteristics of radiation workers with lens opacity]. *Zhonghua Lao Dong Wei Sheng Zhi Ye Bing Za Zhi*. 2024 Oct 20;42(10):743-745. Chinese. doi: 10.3760/cma.j.cn121094-20230609-00200. PMID: 39472136.

- [4] LITTLE M P, AZIZOVA T V, RICHARDSON D B, et al. Ionising radiation and cardiovascular disease: systematic review and meta-analysis [J]. *BMJ*, 2023, 380: e72924.
- [5] Djokovic J, Jankovic S, Milovanovic A, Bulat P. Chromosomal Aberrations, Micronuclei, Blood Parameters and Received Doses in Workers Exposed to Ionizing Radiation. *Med Lav*. 2023 Aug 2;114(4): e2023036. doi: 10.23749/mdl.v114i4.14280. PMID: 37534426; PMCID: PMC10415844.
- [6] National Health Commission of the People's Republic of China. Health requirements and surveillance specifications for radiation workers: GBZ 98-2020 [S]. Beijing: Standards Press of China; 2020.
- [7] Geng F. Comparison of detection methods and analysis of population characteristics for peripheral blood lymphocyte of radiation workers [D]. North China University of Science and Technology; 2024.
- [8] Liu G, Zhang R, Li Y, Wu XQ, Niu LM, Liu YY, Zhang X. Study of Low-Dose Radiation Workers Ionizing Radiation Sensitivity Index and Radiation Dose-Effect Relationship. *Health Phys*. 2022 Oct 1;123(4):332-339. doi: 10.1097/HP.0000000000001593. Epub 2022 Jul 15. PMID: 35775597.
- [9] Farkas G, Kocsis ZS, Székely G, Kenessey I, Polgár C, Jurányi Z. Spontaneous Chromosomal Aberrations in Lymphocytes and Development of Tumor in Hospital Workers. *Anticancer Res*. 2022 Feb; 42(2):1059-1064. doi: 10.21873/anticancer.15567. PMID: 35093907.
- [10] Qian QZ, Cao XK, Shen FH, Wang Q. Effects of ionising radiation on micronucleus formation and chromosomal aberrations in Chinese radiation workers. *Radiat Prot Dosimetry*. 2016 Feb; 168(2):197-203. doi: 10.1093/rpd/ncv290. Epub 2015 Jun 17. PMID: 26084304; PMCID: PMC4884887.
- [11] Cardoso RS, Takahashi-Hyodo S, Peitl P Jr, Ghilardi-Neto T, Sakamoto-Hojo ET. Evaluation of chromosomal aberrations, micronuclei, and sister chromatid exchanges in hospital workers chronically exposed to ionizing radiation. *Teratog Carcinog Mutagen*. 2001; 21(6):431-9. doi: 10.1002/tcm.1030. PMID: 11746256.
- [12] Hu X, Xing YH, Yuan HM. Survey on chromosome aberration rate of peripheral blood lymphocytes among radiological workers in Hunan Province [J]. *Journal of Occupational Health and Emergency Rescue*. 2023; 41(1):85-87.
- [13] Fu Q, Wang GH, Wang Q, Zhu JQ. [Analysis on chromosome aberration rate, micronucleus cell rate and related factors of 3021 radiation workers in Changzhou]. *Zhonghua Lao Dong Wei Sheng Zhi Ye Bing Za Zhi*. 2018 Oct 20; 36(10):759-761. Chinese. doi: 10.3760/cma.j.issn.1001-9391.2018.10.010. PMID: 30541198.