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Research article

Thyroid function and hematological alterations in cardiac catheterization workers: a pre-post observational study on x-ray exposure

Haliz Hussein[1], Hazhmat Ali[2,*], Zeki Mohamed[3], Majeed Mustafa[4], Khairi Abdullah[5], Asaad Alasady[1] and Mayada Yalda[6]

[1] Department of Anatomy, Biology, and Histology, College of Medicine, University of Duhok, Duhok, 42001, Iraq
[2] Department of Medical Physiology and Pharmacology, College of Medicine, University of Duhok, Duhok, 42001, Iraq
[3] Department of Medicine, College of Medicine, University of Duhok, Duhok, 42001, Iraq
[4] Department of Anesthesia, College of Health Sciences, University of Duhok, Duhok, 42001, Iraq
[5] Department of Water Resources, College of Engineering, University of Duhok, Duhok, 42001, Iraq
[6] Department of Pathology, College of Medicine, University of Duhok, Duhok, 42001, Iraq

* **Correspondence:** Email: hazhmat.ali@uod.ac; Tel: +9647504683697.

Abstract: Ionizing radiation is a common health risk encountered by healthcare professionals. Previous studies highlighted the potential adverse effects of X-ray exposure, such as metabolic dysfunctions, radiation-induced biological changes, and a susceptibility to infection. The present study examined the long-term effects of radiation exposure on the hematopoietic system and thyroid functions. A cohort of 40 healthcare professionals of various professions working in the cardiac catheterization center at Azadi Teaching Hospital were recruited for this study. After their consent, the necessary data were taken, and blood specimens were collected for the laboratory investigations. The recruits were divided based on x-ray exposure into pre- and post-exposure groups. Concerning the hematological parameters, no significant differences were observed between the groups, except MCH, which was statistically elevated in the post-exposure group ($p = 0.000$). Among the thyroid hormones, only free T4 was significantly increased in the post-exposed subjects ($p = 0.000$) as compared to non-exposed controls. Moreover, a positive correlation was observed between the ionizing radiation exposure dosage and T4 elevation ($r = 0.362$, $p = 0.02$). The findings collectively highlight the remarkable impact of long-term radiation exposure on thyroid functions and some hematological parameters. Therefore, regular monitoring of health professionals is suggested to avoid the detrimental effects of radiation on human health.

Keywords: ionizing radiation; cardiac catheterizations; radiation risk; thyroid function; hematological parameters

1. Introduction

Cardiac catheterization is a common medical procedure used for the diagnosis and treatment of various heart conditions. It involves fluoroscopy, an X-ray imaging technique, which provides a real-time visualization during catheter insertion. While this technology has proven invaluable in clinical practice, it also exposes medical workers to ionizing radiation, which can lead to various biological effects [1]. Among the most concerning health risks for healthcare professionals working with X-ray equipment are potential hematological and thyroid disorders, both of which are known to be sensitive to radiation exposure [2].

The long-term effects of ionizing radiation (IR) on the health of cardiac catheterization workers have been studied in various parts of the world; however, limited data exists for healthcare professionals in the Kurdistan Region of Iraq, particularly in Duhok city. Given the increasing frequency of cardiac procedures in this region, there is a need to assess the possible hematological and thyroid-related health risks that encounter these workers [3].

Hematological changes, including alterations in the blood cell count and thyroid dysfunction, such as hypothyroidism or hyperthyroidism, have been documented in individuals exposed to ionizing radiation. These health conditions can have significant clinical consequences, thereby affecting worker health, performance, and their overall well-being [4]. The thyroid is particularly sensitive to radiation, and disturbances in its function can lead to metabolic issues, while radiation-induced hematological changes may impair immune function and wound healing and increase the susceptibility to infections [5].

The long-term adverse effects of IR exposure on various organs of the body have been extensively studied. A systematic review that analyzed the possible adverse effects of radiation exposure to thyroid, eye, and hands among interventional cardiology (IC) staff indicated that the aforementioned body parts were likely to be exposed to radiation due to the limited use of personal protective equipment (PPE). Despite more radiation doses being within the recommended levels, there are concerns about the high incidence of cataracts among the IC staff. Therefore, safety practices should strictly be implemented, including the regular use of PPE, maintaining a safe distance from the instruments, and ensuring proper instrument positioning [6]. Some occupational exposures are related to fetal death, congenital anomalies, and fertility disorders. A study reported that an exposure to ionizing radiation is linked to a higher risk of miscarriage, though not stillbirth [7]. Another study reported that genotoxic effects were observed in both the blood and buccal mucosa cells of workers exposed directly or indirectly to IR. Moreover, lifestyle and socioeconomic factors correlate with the increased risk of developing these effects [8].

The present study aims to investigate the potential effects of X-ray exposure on the hematological and thyroid parameters of healthcare workers (HCWs) at the cardiac catheterization center in Azadi Teaching Hospital in Duhok City. The findings could provide crucial insights into the health risks of ionizing radiation and contribute to appropriate protective measures and guidelines for medical professionals in the region.

2. Materials and methods

2.1. Study population

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and was approved by the Institutional Review Board (IRB) (ref. number 22062021–6–10). In this observational study, forty healthcare workers of different professions (cardiologists, nurses, radiologists, and technicians) were recruited of both genders (38 males and 2 female), aged 20 to 49 years. All subjects were occupationally exposed to different levels of IR for at least one year. Upon their permission, informed consent was obtained from every participant. The information needed for each participant after they were briefed on the experimental specifics and study scope was recorded.

2.2. X-ray dosage calculation

After a year of exposure to X-rays, the cardiac catheterization workers' absorbed doses were measured using the OSL In-Light dosimeter (LANDAUER Scitek, Glenwood, USA). The radiation dose received by the workers ranged from 0.08–30.92 mSv, with a mean of 6.052 (0.983) mSv over time.

2.3. Specimen collection

All study participants had their blood drawn according to the established procedures. Each person's venous blood sample was collected using disposable syringes. Five ml of whole blood was collected from each individual in two different intervals, before and after one year of exposure to X-rays. Then, each sample was divided into two separate collection tubes. The samples with EDTA anticoagulants were sent for a hematological analysis, whereas the remaining blood was centrifuged at 1500 rpm for 5 minutes to obtain serum for biochemical examination.

2.4. Hematological parameters

To assess the potential effects of radiation on the blood parameters, a complete blood count (CBC) was performed. It includes a panel of markers such as white blood cell (WBC) count, red blood cell (RBC) count, hemoglobin (Hb), hematocrit (PCV), mean cell volume (MCV), mean cell hemoglobin (MCH), mean cell hemoglobin concentration (MCHC), red cell distribution width (RDW), Platelet count, Neutrophils, Lymphocytes, and Monocytes. Each sample underwent a CBC analysis using an automated hematology analyzer (Swelab Alfa basic, Boule medical) at the Azadi Teaching Hospital laboratory.

2.5. Thyroid function test

To evaluate the impact on thyroid function, 1–2 milliliters of blood were collected into lithium heparin tubes. The levels of thyroid-stimulating hormone (TSH), free triiodothyronine (fT3), and free thyroxine (fT4) were measured for all the participants at the beginning and end of the one-year study period.

2.6. Statistical analysis

A statistical analysis was performed using the Statistical Package for Social Sciences (SPSS, version 26). The data were expressed as mean ± standard deviation. The P values were calculated to estimate the statistical differences between the study groups. P values of 0.05 or less were considered statistically significant, whereas p = 0.01 or less were considered highly significant.

3. Results

The demographic characteristics of the study participants are illustrated in Table 1. Forty healthcare workers (HCWs) of both genders, with an age range of 20–49 years, were recruited for this study. Among the enrolled subjects, 15% were physicians and 10% were anesthetists. All other professions (nurses, radiographers, and technicians) represented a total of 75%, with 25% for each profession, respectively. The majority of the subjects (50%) had the longest duration of service in the radiology sector (11–15 years), followed by 35% of the subjects with 1–5 years, and 15% of the subjects with 6–10 years of service. After one year of exposure to IR, the subjects were evaluated for the absorbed dose. Accordingly, they were categorized into three categories: subjects who received 1–9 mSv (low–dose), subjects who received 10–19 mSv (intermediate dose), and individuals with an absorbed dose > 20 mSv (high dose). Most subjects (75%) received a low dose after one-year post-exposure, followed by 15% of subjects with a high dose, and 10% of subjects with the intermediate dose.

Table 1. Demographic features of the study participants.

Variables	Groups	Frequency	Percent
Absorbed dose (mSv)	Low–dose	20	75
	Intermediate	4	10
	High–dose	6	15
Age (years)	20–29	8	20
	30–39	10	25
	40–49	22	55
Service (years)	1–5	14	35
	6–10	6	15
	11–15	20	50

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Variables	Groups	Frequency	Percent
Occupation	Physician	6	15
	Anesthetists	4	10
	Nurses	10	25
	Radiographers	10	25
	Technicians	10	25
Gender	Male	38	95
	Female	2	5
	Total	40	100

To explore the effects of IR on the hematopoietic system, the subjects were categorized into two groups: before exposure to IR (pre-exposure) and after one year of exposure (post-exposure). The blood specimen of each subject was analyzed for the CBC by estimating a panel of hematological markers that represent the cellular components of blood, as indicated in Table 2. No statistically significant differences were found in the hematological parameters between the two groups except for the MCH, which was substantially elevated in the post-exposure group as compared to the control group ($p = 0.000$).

Table 2. Hematological parameters between study groups.

Variables	Pre-exposure (Mean ± SD)	Post-exposure (Mean ± SD)	*p* value
Hemoglobin g/dl	14.99 ± 1.27	15.48 ± 1.18	0.24
RBC x 10^{12} /l	5.27 ± 0.31	5.31 ± 0.29	0.65
PCV%	41.28 ± 3.40	41.73 ± 2.13	0.64
MCV (fl)	76.18 ± 10.90	75.26 ± 9.77	0.77
MCH (pg)	28.57 ± 2.58	75.26 ± 9.77	0.000
MCHC g/dl	36.51 ± 1.05	36.35 ± 1.06	0.57
RDW%	10.83 ± 1.06	11.06 ± 0.88	0.48
Platelet count x 10^9/l	205.10 ± 50.00	235.05 ± 66.04	0.12
WBC x 10^9/l	6.38 ± 1.49	6.69 ± 1.52	0.55
Neutrophils 10^9/µl	3.635 ±0.8343	3.76 ± 0.71	0.57
Lymphocytes 10^9/µl	3.63 ± 0.82	3.29 ± 0.97	0.12
Monocytes 10^9/µl	0.51 ± 0.16	0.51 ± 0.21	1.00

To examine the impact of IR on the thyroid gland, sera samples of the recruited individuals were evaluated for thyroid functions including fT3, fT4, and TSH. Both the fT3 and the TSH displayed a remarkable elevation in the post-exposure group but was not statistically significant. However, the fT4 was substantially elevated (p = 0.000) compared to the pre-exposed controls, despite being within the normal range (Table 3).

Table 3. Thyroid functions in pre and post-exposure groups.

Variables	Pre-exposure (Mean ± SD)	Post-exposure (Mean ± SD)	*p* value
TSH (uIU/ml)	1.65 ± 1.31	1.979 ± 0.974	0.081
fT3 (nm/L)	2.32 ± 0.03	3.09 ± 1.911	0.070
fT4 (nm/L)	95.51 ± 8.70	134.54 ± 37.43	0.000

Descriptive statistics was used to show the frequency of subjects with normal thyroid functions (euthyroid), hypothyroidism, and hyperthyroidism (Table 4). Based on the TSH findings, 95% of subjects had a normal thyroid profile, with only 5% of subjects with hypothyroidism, whereas no individual was recorded with hyperthyroidism. Concerning the fT3 levels, 35% of the subjects had elevated values compared to the 65% of subjects with normal fT3 values. The same trend was observed for the fT4 values, where most of the study population (75%) had normal values compared to the 25% of subjects who recorded elevated fT4 levels.

Table 4. Thyroid status among study subjects.

Variables	Groups	Frequency	Percent
TSH	Euthyroid	38	95
	Hypothyroidism	2	5
	Hyperthyroidism	0	0
fT3	Normal	26	65
	Elevated	14	35
fT4	Normal	30	75
	Elevated	40	25

To further validate the effect of IR on thyroid functions, the Pearson correlation coefficient was used to display the association between the dose-absorbed and the thyroid hormones. As shown in Table 5, there was a remarkable positive correlation between the IR absorbed dose and the fT4 values (r = 0.362), which was statistically significant (p = 0.02). Positive correlations were also observed between both the TSH and fT3 values with the absorbed dose; however, they were not statistically significant.

Table 5. Pearson correlation coefficient between dose and thyroid functions. Results are expressed as r and p values.

Variables \ Dose		
TSH	***r*** value	*p* value
fT3	0.281	0.07
fT4	0.136	0.39
TSH	0.362	0.02

4. Discussion

IR is considered one of the most common occupational risk factors in various professions, most notably health personnel exposed to radiation from numerous sources, including x-rays using radiological equipment. Despite implementing extra protection measures and regulations, they represent the largest group of workers at risk for developing serious diseases, ranging from minor issues to organ failure [9]. Numerous retrospective cohort studies analyzed the impact of a low-dose exposure to IR among HCWs. It was concluded that the thyroid gland seems to be the most radiosensitive organ that could eventually result in organ damage upon chronic long-term exposure [10]. The present study aimed to investigate thyroid functions and a panel of hematological parameters in HCWs working in the Radiology Department of the Azadi Teaching Hospital in Duhok who were exposed to radiation due to the nature of their occupation.

Concerning thyroid functions, the study results indicated that the T4 levels was substantially elevated in the sera of workers post-exposure. Both T3 and T4 showed elevated levels but were not statistically significant. Despite the existence of numerous literature concerning the impact of radiation exposure on thyroid function, the findings are somehow conflicting. Concerning significant T4 elevation post-exposure, our results are consistent with previous studies. A study that examined thyroid function in the sera of 121 healthcare workers reported increased fT4 levels and a decrease in the fT3 levels, with no TSH variations detected in the sera of individuals exposed to low-dose radiation. This variation in thyroid function could result in functional or organic diseases [11]. Another study highlighted that the fT3 and fT4 levels were significantly elevated in the sera of workers exposed to higher annual IR doses (6–20 mSv) compared to the low-exposed group (1–6 mSv). Moreover, no significant alteration was observed in the TSH levels [12]. Workers with over 20 years of service exhibited elevated abnormal rates of thyroid functions and chromosome aberrations compared to groups with shorter service lengths [13].

It is crucial to highlight that the majority of published research emphasized thyroid dysfunction as a potential implication of radiation exposure and reduced thyroid status findings are contradicting to some extent. A study conducted on 518 radiation-exposed workers at Wuhan Hospital indicated that low-dose exposure to IR was positively correlated with total T4 (tT4) and fT4 but negatively with total T3 (tT3) and TSH. Moreover, the greater the age and the dose, the higher the risk for thyroid dysfunction [14]. A pilot study conducted on 46 HCWs exposed to IR concluded that the TSH levels were significantly elevated in 7.1% of workers without fT3 and fT4, thus suggesting an increased risk of subclinical hypothyroidism in people exposed to low-dose radiation [15]. A retrospective cohort study reported a substantial decline in the T3 and T4 levels but no variation in the TSH levels was detected in the exposed workers. Furthermore, a chronic exposure to IR seems to be associated with reduced T3 and T4 levels [16].

In addition to clinical studies which investigated the impact of irradiation on thyroid function, in vivo studies have thoroughly documented the same notion. Fujimoto and colleagues indicated that thyroid in neonatal rats exposed to x-radiation at different intervals demonstrated morphological alterations represented by smaller-than-normal follicular cells. Such changes were consistent with a significant elevation in the TSH levels and a remarkable reduction in Thyroglobulin (Tg) mRNA and protein expression [17]. Nadol'nik et al. indicated that the thyroid gland in radiation-exposed experimental rats demonstrated a reduced diameter of follicles, follicular epithelia, and the number of thyrocyte ultrastructure suggested thyroid dysfunction [18]. Despite the inconsistent clinical and in vivo literature, it can be concluded that thyroid dysfunction is one of the common consequences of chronic radiation exposure.

Next, it is crucial to shed light on the precise mechanisms of the potential detrimental impact of radiation exposure on the thyroid gland. First, x-rays utilize IR and can induce DNA damage that impairs the replication and transcription processes in thyroid follicular cells, thus resulting in cell dysfunction and even apoptosis. Therefore, a chronic exposure substantially reduces the ability of cells to synthesize thyroid hormones [19]. Second, IR may interfere with the iodine uptake by thyroid cells critical for T3 and T4 synthesis, leading to hypothyroidism. It may also inhibit enzymes essential for thyroid hormone synthesis, such as thyroid peroxidase [20]. Third, a chronic exposure to IR has been associated with autoimmune dysregulation. This may lead to the production of autoimmune antibodies such as anti-thyroid peroxidase antibodies (anti-TPO) which targets the thyroid gland, subsequently leading to autoimmune thyroiditis [21]. Lastly, a long-term exposure is associated with an increased risk of developing malignant and benign thyroid nodules that eventually alter thyroid functions [22].

Since the cellular components of the blood are considered sensitive biomarkers for low-dose IR exposure, a panel of hematological parameters has been measured in this study. None of the parameters displayed any significant difference in the blood specimens of the HCW pre- and post-exposure. Although numerous studies have explored the impact of IR on the hematopoietic system, no consistent findings have been documented. A study reported decreased levels of WBC count, neutrophils, and hemoglobin in HCW exposed to low-dose radiation [23]. However, others reported a significant elevation in the erythrocyte count and a substantial decrease in the platelet count in the radiation-exposed HCW group [24]. In vivo studies indicated that hematopoiesis was elevated in cyclooxygenase-2-deficient (COX-2 KO) mice and was attenuated after radiation exposure [25]. Despite the absence of non-concluding evidence, radiation seems to exert noticeable effects on hematopoiesis that may appear in the long term.

Despite the conflicting results concerning the effects of radiation exposure on hematological parameters, it is apparent that the hematopoietic tissues are also considered radiation-sensitive. Therefore, it is essential to understand the precise mechanism behind these alterations. Long-term exposure affects the blood parameters primarily through bone marrow damage, which is the site of blood cell production. Radiation induces DNA damage, oxidative stress, and apoptosis, particularly in rapidly dividing hematopoietic stem cells, leading to myelosuppression [26]. This results in leukopenia, thrombocytopenia, and anemia, thus impairing the physiological function and reducing the oxygen-carrying capacity [27]. Chronic exposure also disrupts cytokine signaling, causes bone marrow fibrosis, damages microvasculature, and increases the risk of hematological malignancies [28].

The findings of this research provide significant implications for the development of effective health monitoring and preventive strategies for individuals exposed to IR. Regular screening protocols should be implemented to detect early markers for radiation-induced organ damage, such as blood parameters and other tissue abnormalities. In that context, some recommendations concerning preventive measures are supported by several professional organizations, including the Asian Pacific Society of Interventional Cardiology, the European Association of Percutaneous Cardiovascular Interventions, and the Society for Cardiovascular Angiography and Interventions. Such recommended methods include minimizing the fluoroscopy time, reducing the number of images taken, utilizing patient dose-reduction technologies, and using protective shielding [29]. These considerations not only enhance the clinical relevance of the research, but also provide a framework for safeguarding the health of vulnerable workers and even patients in radiation-affected areas.

While the current study significantly contributes to the understanding of regional health status, it has certain limitations. The recruitment of forty healthcare workers from various occupations results in a relatively small sample size. This study was conducted at the primary and only teaching hospital in the district, where the total number of active healthcare workers is just forty-two. Consequently, 95% of potential participants were enrolled in this research. Additionally, it proved challenging for the researchers to maintain follow-ups with the participants over one year. Therefore, future studies should aim to expand the sample size to enhance the validity of the results. In addition to assessing thyroid and hematological parameters, measurement of other biochemical markers, such as liver and renal function, can provide more useful data concerning the effect of radiation on various body systems. Despite the current limitations, the findings of this study hold a substantial relevance in the field of medical biophysics within our region and will serve as a valuable resource for future research.

5. Conclusions

In conclusion, the study findings suggest that a long-term exposure to IR, regardless of the dose, seems to have a significant impact on thyroid functions. Although fT4 was the only parameter significantly elevated in IR-exposed HCWs, the difference in the fT3 and TSH levels was also apparent. Regarding the hematological parameters, although no significant changes were observed between study groups except the MCH, it doesn't exclude its influence on the hematopoietic system. Additional studies are required to further explore the effects of IR by considering aspects that could establish solid findings, such as increasing the sample size of HCWs, including additional thyroid parameters, and grouping the study participants based on the IR dosage. It is recommended that extra-protection measures are implemented by the health authorities to protect the health personnel from the detrimental effects of radiation by regularly monitoring workers for laboratory investigations such as thyroid function tests.

Use of generative-AI tools declaration

The authors declare they have not used artificial intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors have no conflict of interest to declare.

Author contributions

Haliz Hussein and Hazhmat Ali conducted the experiments and drafted the manuscript. Zeki Mohamed analyzed the data. Majeed Mustafa and Khairi Abdullah collected data and recruited patients for the study. Asaad Alasady and Mayada Yalda conceptualized the study, performed critical analysis, and edited the manuscript. Hazhmat Ali supervised the project.

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