ORIGINAL ARTICLE

Association of occupational radiation exposure with DNA damage and thyroid-parathyroid function among radiology workers in Iraq

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Abstract

Background: Occupational workers in radiation fields are routinely exposed to low-to-moderate ionizing radiation, which may lead to biological effects such as genetic damage and disturbances in metabolic and hormonal functions. *Aim and Objectives:* This study aimed to assess the impact of occupational ionizing radiation exposure on DNA damage and the functional integrity of the thyroid and parathyroid hormones among radiology workers in Iraq. *Material and Methods*: This comparative cross-sectional study comprised 82 healthcare workers [age range: 22-52 years exposed to low-dose ionizing radiation (1-35 years)] in the radiology department and 75 healthy controls (age range: 25-50 years). Serum 8-hydroxy-2'-deoxyguanosine (8-OHdG) levels were measured using Enzyme-Linked Immunosorbent Assay, and thyroid function tests [thyroid stimulating hormone (TSH), T_3, T_4], serum calcium, and Parathyroid Hormone (PTH) levels were assessed using a DiaSorin analyzer. The Mann-Whitney U test was used for group comparisons, and Spearman correlation analysis was used to evaluate relationships. *Results:* Radiology workers showed significantly higher levels of DNA damage (30.09 vs. 15.31 ng/mL, $p<0.001$), fasting blood glucose (97.50 vs. 92.00 mg/dL, $p = 0.004$), and T_3 (2.04 vs. 1.60 ng/mL, $p < 0.001$) compared to controls. PTH (37.98 vs. 41.56 pg/mL, $p = 0.021$) and TSH (2.32 vs. 2.32 µIU/mL, $p = 0.001$) levels were significantly lower. A positive correlation was found between study duration and fasting blood glucose ($r = 0.277$, $p = 0.012$). *Conclusion*: Occupational exposure to ionizing radiation is associated with DNA damage, glucose metabolism disorders, and thyroid-parathyroid function changes in radiology workers. Due to the cross-sectional study design, a causal relationship cannot be established; prospective studies are needed to confirm the findings.

Keywords: Occupational radiation exposure, DNA damage, Thyroid function, Parathyroid hormone, Radiology workers, Biomonitoring.

Introduction

Ionizing radiation possesses a considerable amount of energy capable of inducing the ionization of biomolecules, as well as water that is present within the tissues or organs exposed to radiation [1]. Medical applications account for 98% of radiation doses from anthropogenic sources, which represents 20% of the total radiation load experienced by the general population. Globally, approximately 37 million nuclear medicine procedures, 3.6 billion diagnostic radiology tests, and 7.5 million radiotherapy treatments are performed each year. Chronic exposure of workers to low doses of ionizing radiation constitutes a critical risk factor for occupational health [2-4]. The high number of workers who are occupationally exposed to ionizing radiation and the increasing rate of cancer survivors require sustainable management patterns to protect them, particularly due to the rising use of medical radiation and the utilization of new radiation technologies [5].

When individuals are exposed to low levels of ionizing radiation over prolonged periods, this presents a significant risk to human health, manifesting as DNA damage, mutations, cellular proliferation, and contributing to the elevation of cancer risk factors. Numerous variables influence the consequences of human exposure to radiation, including the individual's age and the organs of the human body that are exposed to ionizing radiation [6, 7]. Reactive oxygen species induce mutagenic activity and DNA lesions in guanine, and a hydroxyl moiety is attached at the eighth carbon of the purine ring, resulting in the creation of the predominant form of the compound 8-hydroxy-deoxyguanosine (8OH dG), which is an indication of oxidative stress and the extent of DNA damage [8,9]. Previous findings have indicated that individuals who are occupationally exposed to low levels of ionizing radiation exhibit a higher frequency of various types of chromosomal aberrations, in addition to elevated serum levels of 8-OHdG. Furthermore, many studies in the literature support the hypothesis that 8OHdG is associated with the pathogenesis of a wide spectrum of diseases, from tumor development to cardiovascular diseases and diabetes [10-12].

Ionizing radiation can create free radicals that cause genetic fragmentation or mutations of cellular DNA strands associated with insulin secretion or glucose regulation, which may be involved in the progression of diabetes [13, 14]. Moreover, ionizing radiation impacts the potential target and radiosensitive organs such as the thyroid and parathyroid glands. This gland synthesizes hormones, protein synthesis, modulates the basal metabolic rate, and other physiological processes, involving developing thyroid hormones T_3 and T_4. Additionally, the thyroid gland secretes the hormone calcitonin, which plays a crucial role in regulating calcium homeostasis [15,16]. Previous research has consistently indicated that exposure to ionizing radiation is correlated with an increased threat of developing positive anti-thyroid antibodies and thyroid cancer [17]. Similarly, exposure to ionizing radiation can negatively influence the function of the parathyroid glands, leading to disorders in the Parathyroid Hormone (PTH) level. These disorders can lead to significant disturbances in calcium metabolism, which may have a substantial impact on both physiological function and skeletal health [18]. However, various research efforts have indicated the health outcomes associated with radiation exposure on the thyroid functionality of medical radiation, occupational, and healthcare workers [5,19]. However, few studies have simultaneously evaluated DNA damage (8-OHdG), thyroid, and parathyroid function among radiology workers in Iraq, and none have examined the correlation with employment duration in this population.

This investigation aimed to characterize the impact of ionizing radiation on exposed workers under ongoing exposure circumstances in radiology settings, and intended to measure how employment circumstances affect health, including radiation-induced oxidative stress, by quantifying serum 8-OHdG concentrations in radiographers as an indicator of oxidative injury and biological markers, and comparing them with levels in non-exposed subjects.

Material and Methods

Subjects

The current study employed a comparative cross-sectional design within the confines of the Radiology Department at Al-Yarmouk Hospital, Iraq, from November to December 2024. All healthcare occupational workers assigned to these fields were invited to participate in the study. A convenience sampling method was then used to recruit those who met the inclusion criteria at Al-Yarmouk Hospital during the study period. This study consisted of two groups which include 82 healthcare workers who came into contact with low doses of ionizing radiation on the job in the radiology department (male and female) with ages ranging from 22-52 years and duration of employment in ionizing radiation (1 to 35 years) in addition, to 75 individuals (male and female) with age ranged between 25-50 years who had never worked in the radiation field. The participants answered a detailed questionnaire featuring personal data, including sex, age, weight, height, Body Mass Index (BMI) [weight (kg)/height (m^2)], smoking and alcohol history, and their medical history (health status, chronic diseases, cancer diseases). Healthcare occupational workers also reported the number of years of employment, the daily duration of exposure (hours), and whether they wore personal protective equipment (Table 1). In contrast, the control individuals had no radiological exposure for therapeutic or diagnostic purposes. In this research, we excluded individuals who had previously received radiotherapy or chemotherapy and those with chronic diseases such as endocrine disorders and parathyroid disorders. Additionally, healthcare occupational workers with thyroid, calcium deficiency, and parathyroid disorders before working in the radiation field were excluded.

Hormonal and biochemical assays

In this study, 8 mL of whole peripheral blood specimens were obtained from each cohort via venipuncture with a disposable plastic syringe and transferred into a disposable gel tube. Each sample

Table 1: Demographic characteristics of the healthcare occupational workers and the control group

Characteristics		Workers (n = 82)	Control (n = 75)
Age (years)		22-52	25-50
Sex		40 Male/42 Female	35 Male/40 Female
Duration of employment (years)		1- 35	Nil
Smoking/nonsmoking		34/48	37/38
Radiation protective suit		54/28	Nil
Daily duration of exposure (hours)		16 (12h per day)/ 66 (6h per day)	Nil
Nature of work	**CT scan**	32	Nil
	X-ray	50	Nil
BMI kg/m²		10-20	9-22

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Health status	**Thyroid disorder**	6	Nil
	Arthralgia	40	Nil
	Erythema	4	Nil
	Ocular burning	10	Nil

Note: Low BMI values reflect the nutritional status of the studied population

was systematically coded and categorized into two parts: the first part was put in a heparinized tube and delivered to the laboratory to perform an Enzyme-Linked Immunosorbent Assay (ELISA), and the second part of the samples was retained in a plain tube to obtain blood serum. The samples were centrifuged at a rotation speed of 3000 revolutions per minute (rpm) for 7 minutes to extract blood serum for subsequent calcium, thyroid gland function tests, and PTH tests, utilizing the DiaSorin analyzer device with Elecsys kits. The levels of 8-OHdG detected in participants' serum were quantified by ELISA in full compliance with the manufacturer's protocol. Serum samples obtained from employees were processed in compliance with the procedures outlined in the kit manual, and a calibration curve was created using a standard series for quantitative evaluation. In the analysis, ELISA plates were coated with 8-OHdG capture antibodies, followed by incubation and non-specific binding blocking. Following the addition of serum samples and standards to the plates, target molecules were identified through the application of a detection antibody and a streptavidin-linked HRP conjugate. Substrate solution was added to commence the chromogenic reaction, and the resultant color intensity, which developed proportionally with 8-OHdG levels, was quantified at 450 nm using a microplate reader; final 8-OHdG levels were validated and quantified using the standard curve formula.

Statistical analysis

Statistical analyses were performed using Statistical Package for the Social Sciences (version 26.0; SPSS Inc., Chicago, IL, USA) software, and the normality of the data distribution was evaluated using the one-sample Kolmogorov-Smirnov test; the analysis revealed that all biochemical parameters exhibited a non-parametric distribution. Consequently, group comparisons were performed using the Mann–Whitney U test to evaluate statistical differences between the Iraqi radiology workers and the control group, with descriptive statistics reported as median, minimum, and maximum values. Correlations between variables were assessed using Spearman's rank correlation coefficient, with a value of p less than 0.05 considered statistically significant.

Results

The radiology workers' group showed higher median levels of DNA damage markers (30.088 ng/ml) than the control group (15.31 ng/ml). The minimum and maximum obtained values for radiology workers and controls were (21.43-100 ng/ml) and (10.47-19.27 ng/ml). The minimum and maximum obtained values for the groups were (11.46-36.4 ng/ml) and (29.8-36 ng/ml). The results demonstrate a significant increase in the median of T_3 in the radiology workers' group (2.04 ng/ml) versus the control group (1.6 ng/ml). The minimum and maximum obtained values for the radiology workers and control groups were (1.02-2.91 ng/ml) and (1.21-1.92 ng/ml). The statistical analysis for these biochemical variables exhibited a highly significant difference ($p < 0.001$). The results also demonstrated higher median levels of Fasting Blood Sugar (FBS) in the radiology workers (97.5 mg/dL) with a range of (65-212 mg/dL) compared to the control group (92 mg/dL); with a range of (83-99 mg/dL), the statistical analysis indicated a significant *p* value (0.004). The radiology workers exhibited a slightly lower PTH levels (37.98) and Thyroid-Stimulating Hormone (TSH) (2.32µIU/m) levels with minimum and maximum values (16.41-53.26) and (0.61-4.03) respectively, versus the median levels of PTH (41.56) and TSH (2.32) of the control group with minimum and maximum values (29.47-52.19) and (1.3-3.75), the result showing significance with a *p* value (0.021) and (0.001), respectively.

The statistical analysis demonstrated that there was no significant difference in levels of glycated Haemoglobin (HbA1c), Ca, and T_4 across the comparative groups, with *p* values of 0.192, 0.181, and 0.38, respectively. The results of this study show statistically significant differences in the comparative analysis of several biochemical parameters between the control and radiology worker groups (Table 2). Also, Table 3 illustrates the gender distribution in the study. Among the total participants (N = 157), males represented 33.1% (frequency = 52), while females represented 66.9% (frequency = 105).

In contrast, this investigation showed a considerable difference in PTH between genders, with *p* value of 0.003, while there was no significant difference in other biochemical parameters (Table 4). The data in Table 5 presents Spearman's rho correlation between duration of employment (years) and biological parameters in the study. Furthermore, the results indicate a positive relationship between duration of employment (years) and FBS, r = 0.277, with a significant p-value of p = 0.012. However, the results show a minimal or weak correlation between work duration (years) and other biological parameters such as TSH, T_3, DNA damage, and Ca. As shown in Figure 1, a weak positive correlation was observed between DNA damage and duration of employment (r = 0.13, p = 0.24), indicating no significant linear relationship.

Table 2: Comparative analysis of biochemical parameters between the control and radiology workers group

Parameters	Control	Workers	*p*
	Median (Min-Max)	Median (Min-Max)	
HbA1c (mg/dl)	4.9 (4.10-5.6)	4.65 (4-7)	0.192
FBS (mg/dl)	92 (83-99)	97.5 (65-212)	0.004
DNA damage (mg/dl)	15.31 (10.47-19.27)	30.088 (21.43-100)	0.000
Ca (mg/dl)	9.4 (8.8-9.7)	9.41 (9-9.8)	0.181
PTH (pg/mL)	41.56 (29.47-52.19)	37.98 (16.41-53.26)	0.021

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TSH (µIU/mL)	2.32 (1.3-3.75)	2.32 (0.61-4.03)	0.001
T_3 (ng/mL)	1.6 (1.21-1.92)	2.04 (1.02-2.91)	0.000
T_4 (µg/dL)	116.1 (106.90-125.7)	114.5 (96.20-133.7)	0.380

HbA1c – Glycosylated hemoglobin; FBS – Fasting blood sugar; DNA – Deoxyribonucleic acid; Ca – Calcium; PTH – Parathyroid hormone; TSH – Thyroid stimulating hormone

Table 3: Gender wise distribution for control and radiology workers group

Gender		Frequency	Percent
Valid	**Male**	52	32.7
	Female	105	66.0
	Total	157	98.7

Table 4: Sex wise distribution and biochemical parameters for control and radiology workers group

Parameter	Male Median	Female Median	*p*
	Min-Max	Min-Max	
HbA1c (mg/dl)	4.6 (4.10-5.60)	4.7 (4-7)	0.674
FBS (mg/dl)	92 (78-212)	99 (65-199)	0.063
DNA damage (mg/dl)	31.239 (22.54-100)	29.243 (21.43-45.12)	0.920
Ca (mg/dl)	9.39 (9-9.8)	9.43 (9-9.8)	0.399
PTH (pg/mL)	34.77 (16.41-53.26)	40.24 (16.41-53.26)	0.033
TSH (µIU/mL)	2.58 (0.61-4.03)	2.26 (0.61-3.98)	0.161
T_3 (ng/mL)	2.1 (1.02-2.91)	2.03 (1.35-2.91)	0.415
T_4 (µg/dL)	116.7 (96.2-133.7)	112.5 (96.2-133.7)	0.288

Table 5: Spearman's rho correlation between duration of employment of radiation workers and other biochemical parameters

Parameters	Duration of employment (years)		HbA1c		FBS		DNA damage		Ca		PTH		TSH		T_3		T_4	
Correlation	*r*	*P*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Duration of employment (years)	1.00	–	-0.12	0.28	0.277*	0.01	0.13	0.24	-0.14	0.22	-0.17	0.12	-0.08	0.46	-0.13	0.24	0.00	0.98
HbA1c	-0.12	0.28	1.00	–	0.04	0.59	-0.16	0.05	-0.11	0.20	-0.04	0.62	0.184*	0.02	0.05	0.52	-0.08	0.32
FBS	0.277*	0.01	0.04	0.59	1.00	–	0.189*	0.02	-0.04	0.61	0.04	0.65	-0.11	0.17	0.03	0.68	-0.10	0.23
DNA damage	0.13	0.24	-0.16	0.05	0.189*	0.02	1.00	–	0.10	0.25	-0.199*	0.02	-0.203*	0.01	0.486*	0.00	-0.01	0.90
Ca	-0.14	0.22	-0.11	0.20	-0.04	0.61	0.10	0.25	1.00	–	-0.13	0.11	-0.13	0.11	0.11	0.20	0.06	0.49
PTH	-0.17	0.12	-0.04	0.62	0.04	0.65	-0.199*	0.02	-0.13	0.11	1.00	–	0.04	0.62	-0.217*	0.01	-0.08	0.33
TSH	-0.08	0.46	0.184*	0.02	-0.11	0.17	-0.203*	0.01	-0.13	0.11	0.04	0.62	1.00	–	-0.16	0.05	-0.09	0.26
T_3	-0.13	0.24	0.05	0.52	0.03	0.68	0.486*	0.00	0.11	0.20	-0.217*	0.01	-0.16	0.05	1.00	–	0.336	<0.001
T_4	0.00	0.98	-0.08	0.32	-0.10	0.23	-0.01	0.90	0.06	0.49	-0.08	0.33	-0.09	0.26	0.336	<0.001	1.00	–

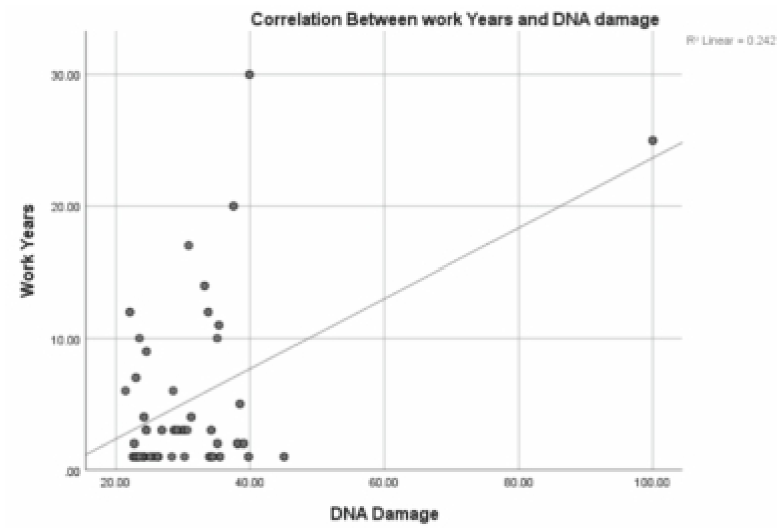

Figure 1: Linear correlation analysis between DNA damage and duration of employment (years)

DNA – Deoxyribonucleic acid

Discussion

This study presents, to our knowledge, the first comprehensive assessment of radiation-induced DNA damage and endocrine dysfunction in radiology workers in Iraq. Our findings demonstrate significant increases in 8-OHdG, altered glucose metabolism, and impaired thyroid-parathyroid homeostasis, suggesting that occupational radiation exposure leads to multisystemic biological effects even at low-to-moderate doses [20,21].

Serum 8-OHdG levels were found to be 96% higher in radiology workers compared to controls, confirming significant oxidative DNA damage due to occupational radiation exposure [22-24]. This finding is biologically consistent; ionizing radiation produces hydroxyl radicals that attack the C8 position of guanine bases, forming 8-OHdG, and this lesion is mutagenic damage associated with G→T transversions [6, 7]. The elevation reported in this study exceeds that reported in occupational studies in Europe [8, 9], which is most likely attributable to the lower rate of thyroid shield use (65.9%) in our study group and older equipment, resulting in higher scattered doses. This research indicates that Iraqi radiology workers may not have developed radioprotective adaptations and may face an increased risk of cancer in the long term. The clinical significance of our 8-OHdG finding is concerning; similar levels have been associated with increased cancer risk and diabetes pathogenesis in other cohorts [10, 11]. The effects of observed DNA damage are not limited to carcinogenesis; oxidative stress and inflammation, consequences of radiation-induced genomic damage, are known triggers of insulin resistance. This mechanistic link is particularly relevant to our finding of elevated fasting blood glucose in radiology workers and suggests that radiation-induced oxidative damage may impair pancreatic β-cell function and insulin signaling pathways [12, 14].

Significantly higher fasting blood glucose levels in radiology workers indicate radiation-induced glucose metabolism disorder. This elevation is mechanistically consistent; ionizing radiation produces reactive oxygen species that can damage pancreatic β-cells, disrupt insulin secretion, and reduce glucose uptake in peripheral tissues [13]. Furthermore, the positive correlation with working time supports the cumulative exposure effect, consistent with the findings of Silva-Júnior *et al.* (2020) [25], who reported dose-dependent glucose dysregulation in healthcare workers. Experimental studies have shown that radiation can negatively affect the functionality and survival of beta cells, inhibit insulin secretion, and contribute to the development of diabetes mellitus [26]. Although the observed increase of 5.5 mg/dL did not reach diabetic thresholds (≥ 126 mg/dL), it represents a clinically significant shift towards prediabetes (≥ 100 mg/dL), with approximately 15% of employees exceeding this threshold. These data suggest that cumulative occupational radiation exposure may contribute to the risk of diabetes and highlight the need for routine glucose screening in radiology personnel with more than 10 years of service.

Significant endocrine changes were observed in radiology employees, including decreased levels of TSH and PTH, along with increased levels of T_3. The decrease in TSH suggests radiation-induced suppression of pituitary-thyroid axis function, most likely due to oxidative stress-mediated damage to thyrotrophic cells or changes in hypothalamic TRH secretion. In contrast, the elevation of T_3 despite TSH suppression is a paradoxical finding and could be explained by radiation-induced changes in deiodinase enzyme activity, increased peripheral conversion of T_4 to T_3, or decreased T_3 clearance [13]. Ionizing radiation produces reactive oxygen species that can activate NF-κB signaling pathways, induce apoptosis, and alter cell membrane receptor sensitivity. Radiation may also affect deiodinase enzymes responsible for converting T_4 to T_3, potentially explaining the elevated T_3 observed despite TSH suppression. These findings are consistent with Cioffi *et al*. (2020), who reported thyroid dysfunction in healthcare workers with cumulative radiation exposure [16]. However, they contradict the findings of Wong *et al*. (2019), who found a decrease in T_3, and this difference may reflect variations in radiation source, exposure duration, or individual sensitivity [27]. The simultaneous decrease in PTH without corresponding changes in serum calcium suggests early parathyroid dysfunction with compensatory mechanisms that maintain calcium homeostasis. Exposure to ionizing radiation can affect parathyroid function by disrupting cellular integrity and reducing hormone production [17]. Clinically, while these endocrine changes are not overtly pathological, they represent subclinical dysfunction that may progress with continued exposure and require regular endocrine monitoring.

The potential clinical significance of our thyroid findings is supported by extensive literature linking radiation exposure to an increased risk of thyroid nodules, hypothyroidism, and carcinoma [28]. Previous studies have shown changes in thyroid function in workers occupationally exposed to ionizing radiation, with exposure significantly affecting levels of TSH, T_3, and T_4 [5,18]. Our observation of T_3 elevation along with TSH suppression parallels the findings of Yang *et al.* [29], who reported abnormal TSH and elevated T_3 with increasing years of service. However, this differs from the study by Keskin (2023), which reported a general T_3 decrease, and this difference may be due to differences in radiation dose rates or individual thyroid sensitivity [30].

Critically, our survey revealed that a significant proportion of radiology technicians did not consistently use thyroid shields or protective equipment throughout their careers, with only 65.9% reporting consistent use of radiation protective clothing. The lack of thyroid shield use is particularly concerning, given that the thyroid gland is highly radiosensitive. This finding is consistent with the increased thyroid sensitivity observed in this cohort. This modifiable risk factor represents a priority intervention target; mandatory thyroid shield use and regular compliance follow-up could significantly reduce radiation - induced endocrine dysfunction. Furthermore, the study demonstrates that ionizing radiation can cause thyroid damage and shows a correlation between age, years of work experience, and abnormal TSH; the rate of TSH, T_3, and T_4 was elevated with increasing years of work experience [23].

Collectively, our findings paint a worrying picture of the multisystemic effects of occupational radiation exposure. The simultaneous increase in 8-OHdG, FBS, and T_3, along with the suppression of TSH and PTH, suggests that radiation-induced oxidative stress may be a common pathogenic mechanism affecting different tissues [6, 7, 12, 13]. While the thyroid's sensitivity to radiation is well known, our data show that the parathyroid glands and pancreatic β-cells are also sensitive. This pattern of multiple endocrine changes observed with genomic damage underscores the need for comprehensive health surveillance rather than organ-specific monitoring in radiology workers. Importantly, the dose-response relationship (correlation of study duration with FBS) suggests that these changes are driven by cumulative exposure, not just acute exposure.

Several limitations must be considered in the evaluation of this study. First, due to the cross-sectional design, a cause-and-effect relationship cannot be established as to whether the observed structural differences are pre-occupational or radiation-induced. Secondly, due to the lack of individual dosimetry data, exposure levels were estimated by study duration rather than cumulative dose, limiting dose-response analyses. Thirdly, the absence of formal power analysis using convenience sampling (n = 157) may affect the reliability of subgroup analyses, posing a risk of selection bias. Finally, potential confounding factors such as diet, lifestyle, and non-occupational radiation could not be comprehensively investigated, and the study was limited to a cross-sectional assessment due to single-timepoint measurement. For these reasons, the findings should be interpreted cautiously, and prospective cohort studies with individual dosimetry follow-up should be focused on to confirm the associations. Despite these limitations, the study has notable strengths. To our knowledge, this is the first study to simultaneously assess DNA damage, glucose metabolism, and thyroid-parathyroid function in an Iraqi occupational cohort. The inclusion of a well-matched control group and the use of valid ELISA and DiaSorin analyzer methods enhanced reliability and reproducibility. The correlation between working time and FBS provides initial evidence of cumulative exposure effects, laying the groundwork for future longitudinal studies. Furthermore, the detailed demographic and occupational data collected allow for contextual interpretation of the findings.

Conclusion

The evaluated biological parameters among radiology workers are essential to estimate future occupational health care records. The results of this study demonstrate that occupational exposure to ionizing radiation is associated with increased DNA damage, metabolic abnormalities, and subclinical endocrine dysfunction in radiology personnel. The positive correlation observed between working time and FBS levels, in particular, points to the cumulative effects of radiation; however, the cross-sectional design of the study prevents the establishment of a definitive cause-and-effect relationship. The data highlight the critical importance of regular health monitoring, preventive strategies, and full adherence to radiation safety protocols in reducing occupational risks. Future research should focus on prospective and longitudinal studies involving individual dosimetry monitoring to assess the effectiveness of preventive measures and long-term clinical outcomes.

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Compliance with ethical standard

This study conformed to the ethical guidelines outlined in the Declaration of Helsinki (1964) and its subsequent amendments. Ethical approval and permission to conduct the study were obtained from the administration of Al-Yarmouk Hospital, Baghdad, Iraq (Approval No.: YH-RD-2024-10-28B, dated October 28, 2024). All participants provided informed written consent prior to enrollment. Data were anonymized to ensure participant confidentiality.

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