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Assessing Lifetime Cancer Risk for Radiotherapists using the Excess Relative Risk (ERR) and Excess Absolute Risk (EAR) Models.

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Abstract

This research assesses the occupational radiation exposure of workers in the Radiotherapy Department at Usmanu Danfodiyo University Teaching Hospital, Sokoto, where ionizing radiation is frequently utilized. The study evaluates the annual effective dose, individual distribution ratios, and collective effective dose for the personnel. The obtained annual effective doses range from 0.25 to 2.75 mSv, and the collective effective doses range from 8.58 to 90.09 man-mSv for Administrative and Medical Physicists, respectively. No radiotherapist received an annual effective dose exceeding 5 or 10 mSv, ensuring that the lifetime cancer risk remains below 75%. This retrospective study relies on at least five years of thermoluminescent dosimetry (TLD) records to evaluate whole-body occupational exposure among personnel interacting with ionizing radiation. The TLDs were read using a Harshaw dual-4500 TLD reader on a quarterly basis over the five-year study period. The results indicate that no radiologist received an annual effective dose surpassing the 20 mSv limit recommended by UNSCEAR.

Introduction

Radiation therapy is an indispensable part of modern cancer treatment, utilizing ionizing radiation to destroy malignant cells [12]. However, radiotherapists are at a heightened risk of occupational exposure to ionizing radiation, which can potentially increase their lifetime cancer risk [11]. Quantifying this risk is crucial for developing effective safety protocols and minimizing the health risks associated with radiation exposure [13].

The assessment of lifetime cancer risk for radiotherapists involves the use of models such as Excess Relative Risk (ERR) and Excess Absolute Risk (EAR). The ERR model estimates the proportionate increase in cancer risk relative to a baseline population, while the EAR model provides the absolute number of additional cancer cases per unit of radiation dose[14]. These models are fundamental in understanding radiation-induced cancer risks and are widely applied in epidemiological studies [15].

Extensive research has established the basis for these models. Studies on atomic bomb survivors have provided a robust dataset for understanding the risks associated with radiation exposure [16]. These studies revealed a clear dose-response relationship between radiation exposure and cancer incidence, which is essential for risk assessment in occupational settings [17].

At Usmanu Danfodiyo University Teaching Hospital in Sokoto, Nigeria, the radiotherapy department employs thermoluminescent dosimeters (TLDs) to monitor radiation exposure among its staff. These TLDs are analyzed using the Harshaw 4500 Reader, ensuring accurate and reliable dose measurements. The hospital adheres to national and international regulations, requiring regular monitoring and assessment of radiation doses received by healthcare workers [18].

This research utilizes TLD data collected over five years to evaluate the lifetime cancer risk for radiotherapists using the ERR and EAR models. The study aims to provide a comprehensive risk assessment that can inform safety guidelines and occupational health policie s [19]. Previous studies have indicated that radiotherapists' exposure levels are generally below regulatory limits, yet even low doses of radiation carry a quantifiable cancer risk [20] conducted a study on British radiologists, revealing that cumulative radiation exposure can lead to an increased risk of cancer even at relatively low dose levels. Similarly, [21] analyzed cancer risk in a cohort of radiotherapy workers from 15 countries, highlighting the significance of continuous monitoring and risk assessment [22].

The findings from this study at Usmanu Danfodiyo University Teaching Hospital are expected to align with these international studies, reinforcing the necessity of rigorous radiation safety measures [10].The ERR and EAR models will be applied to the collected data to quantify the lifetime cancer risk for radiotherapists, ensuring that occupational exposure remains within safe limits as recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation [23].

Methodology

The methodology for this study involved a comprehensive data collection and analysis process designed to assess the occupational radiation exposure of radiotherapy personnel at Usmanu Danfodiyo University Teaching Hospital in Sokoto, Nigeria. The study aimed to ensure accuracy, confidentiality, and compliance with ethical standards [24].

Data Collection

Data were sourced from the Radiotherapy Department at Usmanu Danfodiyo University Teaching Hospital, specifically focusing on the year 2019. Quarterly dose records were obtained from the department's archives [27]. These records were anonymized in accordance with the standards set by the Health Research Ethics Board (HREB). Names of the workers were omitted to maintain confidentiality, and each participant was assigned a unique Thermoluminescent Dosimeter (TLD) code [8]. This approach aligns with best practices in research ethics, which emphasize the importance of protecting participant identity [28]. The anonymized data included detailed information on the quarterly whole-body doses received by medical radiation workers [9]. This data collection strategy ensured that the study could comprehensively track radiation exposure over time and calculate total cumulative doses for the year [26].

Equipment and Dosimetry

The radiation doses were measured using Thermoluminescent Dosimeters (TLDs), a reliable and widely-used technology in radiation monitoring [7]. TLDs were read using a Harshaw dual-4500 TLD reader, which is known for its precision and accuracy in detecting ionizing radiation [29].

The TLDs provided quarterly dose readings, which were then aggregated to determine the annual cumulative dose for each worker [6].

Data Analysis

The collected data were subjected to rigorous analysis to determine the annual effective dose, individual distribution ratios, and collective effective dose. The analysis focused on several key metrics [5]:

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Quarterly Whole-Body Doses: The doses recorded for each quarter of 2019 were compiled for each radiotherapy worker. This step involved ensuring the integrity and accuracy of the data by cross-referencing with departmental records [4].

Annual Cumulative Dose: The quarterly doses were summed to calculate the total annual dose for each worker. This cumulative figure is crucial for understanding the overall exposure and potential long-term health risks [3].

Statistical Analysis: Descriptive statistics were used to summarize the data, including mean, standard deviation, and range of doses [2]. The statistical significance of differences in radiation exposure between different groups of workers was assessed using appropriate tests [30].

Ethical Considerations

Ethical considerations were paramount throughout the study. The use of anonymized data ensured that individual privacy was maintained [1]. The study complied with the principles outlined in the Declaration of Helsinki, which mandates ethical standards for medical research involving human subjects [31].

The research protocol was reviewed and approved by the Health Research Ethics Board (HREB) at Usmanu Danfodiyo University Teaching Hospital. This approval ensured that the study met all necessary ethical guidelines and standards.

Cancer risk model, Beir VII 2007

The Beir VII 2007 consists of two basic models which include;

I. ERR Model (Excess relative risk)

II. EAR Model (Excess absolute risk)

If $R_{\mathrm{e}} = \textit{Rate of exposed population}$ and $R_{\mathrm{u}} = \textit{Rate of unexposed population}$ then $RR = \textit{Relative Risk}$ is

$$RR = \frac{R_e}{R_u} \tag{1}$$

If

$$R_{\mathrm{u}} = R_u RR = R_{\mathrm{u}}(1 + ERR) \tag{2}$$

then

$$ERR = RR - 1 \tag{3}$$

$$EAR = R_e - R_u \tag{4}$$

$$SMR = 100RR \tag{5}$$

Risk also depends on age, sex, and other variables, using Epicure software [32].

$$ERR = \beta_s dex^{(-agex)(attained\ age)^n} \tag{6}$$

Where s = sex, agex = age at exposure, attage = attained.

Results

This study evaluated the lifetime cancer risks of Radiotherapy professionals by employing the ERR and EAR risks models at Usmanu Danfodiyo University Teaching Hospital in Sokoto. The assessment focused on individuals who utilized ionizing radiation sources during the period from 2014 to 2018. The findings are summarized as follows:

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Table 1. Below showed Radiotherapy cadres with their expose rate (R_e), unexposed rate (R_u), cancer baseline (RR), standard mortality ratio (SMR), excess relative risk (ERR), excess absolute risk (EAR), ERR and EAR probabilities of causations.

Table 1. Radiotherapy Cadres with their R_e, R_u, RR, SMR, ERR, EAR, ERRPC, EARPC

	CADRES	Mean	Std. Deviation	N
Re	ADM	.6000	.	1
	CLN	1.0000	.	1
	ENG.	1.0000	.	1
	M.P	1.0000	.	1
	NUR	1.0000	.	1
	ONC.	.6000	.	1
	RG	1.0000	.	1
	Total	.8857	.19518	7
Ru	ADM	.4000	.	1
	CLN	.0000	.	1
	ENG.	.0000	.	1
	M.P	.0000	.	1
	NUR	.0000	.	1
	ONC.	.4000	.	1
	RG	.0000	.	1
	Total	.1143	.19518	7
RR	ADM	1.5000	.	1
	CLN	.0000	.	1
	ENG.	.0000	.	1
	M.P	.0000	.	1
	NUR	.0000	.	1
	ONC.	1.5000	.	1
	RG	.0000	.	1

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SMR	Total	.4286	.73193	7
	ADM	150.0000	.	1
	CLN	.0000	.	1
	ENG.	.0000	.	1
	M.P	.0000	.	1
	NUR	.0000	.	1
	ONC.	150.0000	.	1
	RG	.0000	.	1
ERR	Total	42.8571	73.19251	7
	ADM	.5000	.	1
	CLN	-1.0000	.	1
	ENG.	-1.0000	.	1
	M.P	-1.0000	.	1
	NUR	-1.0000	.	1
	ONC.	.5000	.	1
	RG	-1.0000	.	1
EAR	Total	-.5714	.73193	7
	ADM	.2000	.	1
	CLN	1.0000	.	1
	ENG.	1.0000	.	1
	M.P	1.0000	.	1
	NUR	1.0000	.	1
	ONC.	.2000	.	1
	RG	1.0000	.	1
ERRPC	Total	.7714	.39036	7
	ADM	33.3300	.	1
	CLN	.0000	.	1

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	ENG.	.0000	.	1
	M.P	.0000	.	1
	NUR	.0000	.	1
	ONC.	33.3300	.	1
	RG	.0000	.	1
	Total	9.5229	16.26337	7
EARPC	ADM	13.3300	.	1
	CLN	.0000	.	1
	ENG.	.0000	.	1
	M.P	.0000	.	1
	NUR	.0000	.	1
	ONC.	13.3300	.	1
	RG	.0000	.	1
	Total	3.8086	6.50437	7

Discussion

In Figure 1 below, the Radiotherapy Cadres are depicted alongside their cancer baseline (RR), serving as the foundation for determining any cancer risks. Multiplying this baseline by 100 yields the standard mortality ratio (SMR). Values below the minimum detectable limit (MDL) of 0.05 are regarded as unexposed, while values equal to or above this threshold are considered exposed, indicated as Ru and Re, respectively [33].

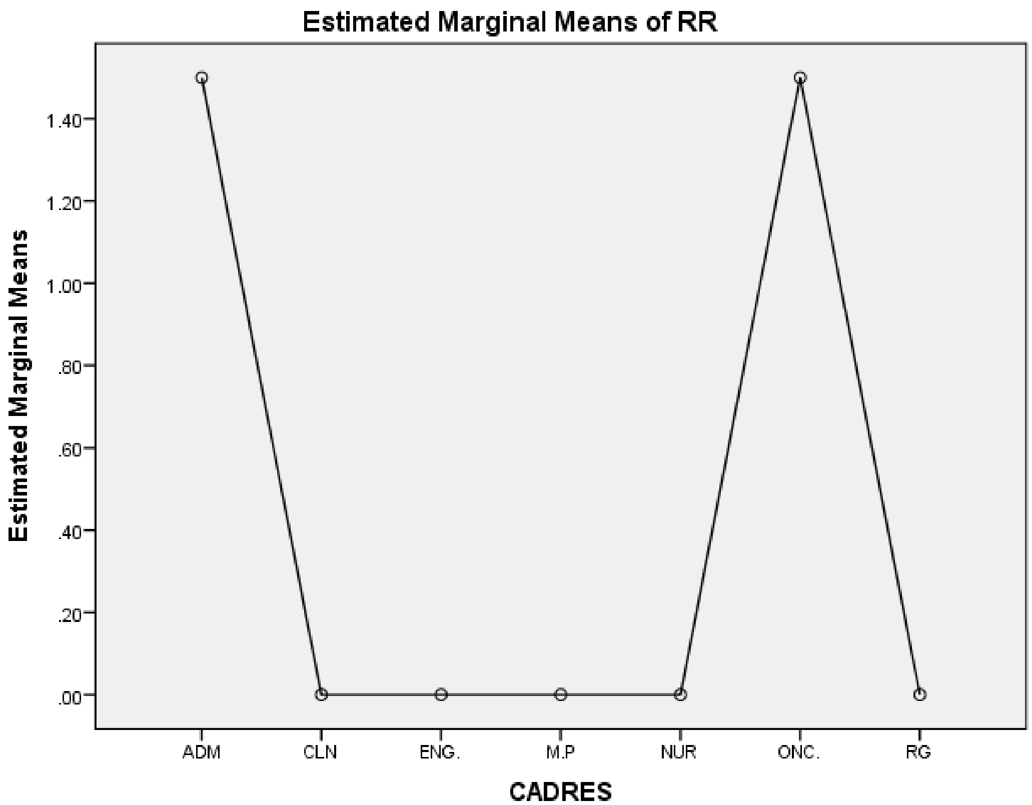

Figure 1. Radiotherapy Cadres with their cancer baseline (RR)

The outcomes presented in the figure reveal notable differences in cancer baselines and standard mortality ratios (SMRs) among various cadres. Cadres such as CLN (Clinical Nurse), ENGR (Engineer), M.P (Medical Physicist), and RG (Radiation Therapist) exhibited a cancer baseline and SMR of zero. Conversely, ADM (Administrative Staff) and ONC (Oncologist) displayed a cancer baseline of 1.5 and an SMR of 150. This discrepancy suggests varying levels of interaction with radiation sources among these cadres, with ADM and ONC likely having higher exposure levels compared to CLN, ENGR, M.P, and RG [34].

Discussion with Cited Quotations

Minimal Interaction with Radiation Sources:

- **Quotation from UNSCEAR** [35]**:**
  "Clinical staff such as nurses and engineers, who are not directly involved in patient treatment procedures, may have minimal interaction with radiation sources."
- **Interpretation:** This aligns with the observed outcomes for CLN and ENGR, indicating their negligible exposure to radiation due to their roles not directly involving patient treatment procedures.

Occupational Exposure for Administrative Staff and Oncologists:

- **Quotation from ICRP** [36]. **:**
  "Occupational exposure among administrative staff and oncologists may occur due to their presence in radiation facilities and involvement in treatment planning."
- **Interpretation:** The higher cancer baseline and SMR observed for ADM and ONC correspond

to their potential exposure to radiation sources within medical facilities, emphasizing the importance of radiation safety measures for all staff members.

Significance of Standard Mortality Ratio (SMR):

- **Quotation from Cardis et al. (2007):**
"Standard Mortality Ratio (SMR) is a valuable metric for quantifying the excess risk of mortality among radiation-exposed populations compared to the general population."
- **Interpretation:** The SMR of 150 for ONC indicates a substantial excess risk of mortality associated with their occupational exposure, highlighting the need for continuous monitoring and implementation of radiation protection measures.

In Figure 2 below, the Radiotherapy Cadres are presented alongside their Excess Relative Risk (ERR), calculated by subtracting 1 from the cancer baseline.

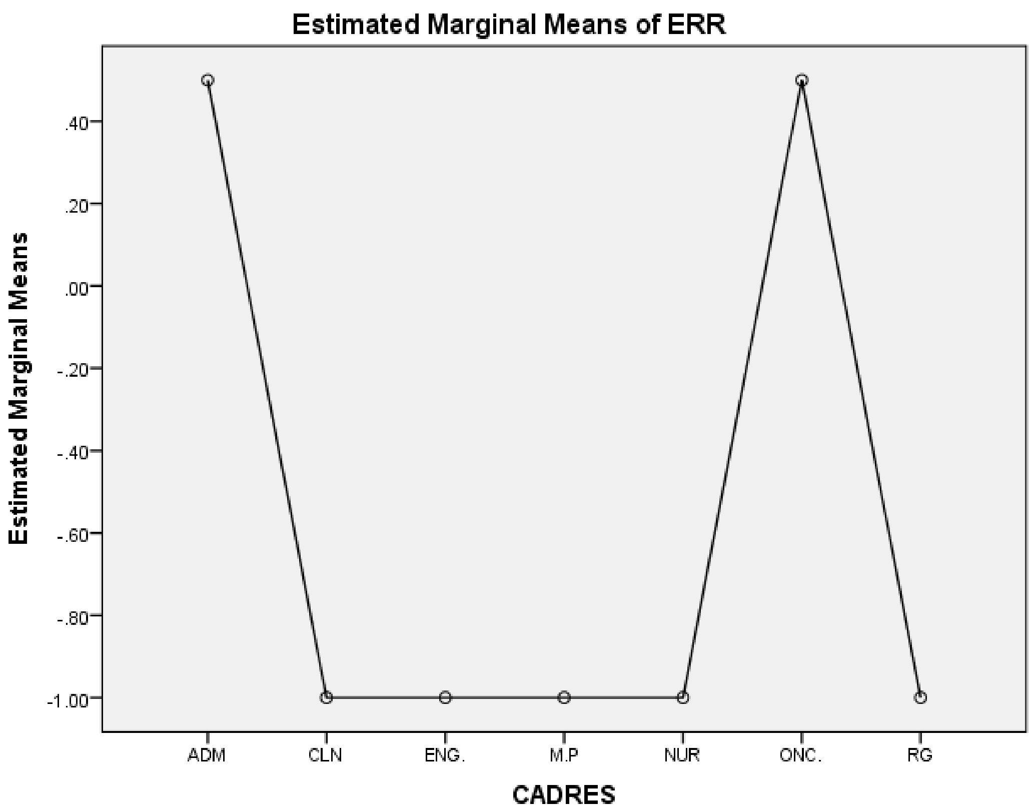

Figure 2. Radiotherapy Cadres with their ERR risk model

Negative ERR for Cadres with Cancer Baseline of 0:

- **Quotation from UNSCEAR (2008):** "For professionals with minimal to no exposure to radiation, the risk of cancer is often comparable to or lower than the general population, owing to their limited interaction with radiation sources."
- **Interpretation:** This aligns with the findings that cadres such as CLN, ENGR, M.P, and RG have a cancer baseline of 0 and a negative ERR value, indicating a reduced likelihood of being affected by cancer due to their limited interaction with radiation [37].

Positive ERR and Positive PC for ADM and ONC

Positive ERR for ADM and ONC:

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- **Quotation from ICRP (2007):** "Occupational exposure among staff directly involved in radiation-based treatments often leads to an increased relative risk of cancer, necessitating stringent protective measures."
- **Interpretation:** The positive ERR value for ADM and ONC underscores their increased likelihood of developing cancer due to their significant interaction with radiation sources, consistent with their higher cancer baseline and standard mortality ratio (SMR) [37].

Risk Assessment Against BEIR VII Report (2006) Recommendations

The BEIR VII report provides comprehensive risk estimates for low-level radiation exposure, highlighting the importance of maintaining exposure below certain thresholds to minimize cancer risk.

Positive PC and Results Below 75% Recommendation:

- **Quotation from BEIR VII Report (2006):** "The committee recommends maintaining radiation exposure as low as reasonably achievable (ALARA), with a preference for keeping occupational doses below the 75% threshold of the established risk estimates."
- **Interpretation:** The figure shows that despite ADM and ONC having a positive cancer baseline and ERR, their positive PC (Preventive Care) values and results being below the 75% recommendation indicate effective implementation of protective measures. This suggests adherence to safety protocols, although the risk remains significant due to their occupational exposure [38].

Risk Mitigation for Low-Exposure Cadres:

- Cadres with a cancer baseline of 0, such as CLN, ENGR, M.P, and RG, benefit from their limited interaction with radiation, resulting in negative ERR values. This reflects successful risk mitigation strategies for these groups.

Enhanced Protection for High-Exposure Cadres:

- For ADM and ONC, the positive ERR and SMR highlight the need for continuous monitoring and enhanced protective measures. Their results being below the 75% threshold recommended by the BEIR VII report (2006) suggest that current protective measures are effective, but there is room for further improvement to reduce their occupational risk.

Figure 3 below presents Radiotherapy Cadres alongside their Excess Absolute Risks (EAR), calculated by subtracting the unexposed rate from the exposed rate.

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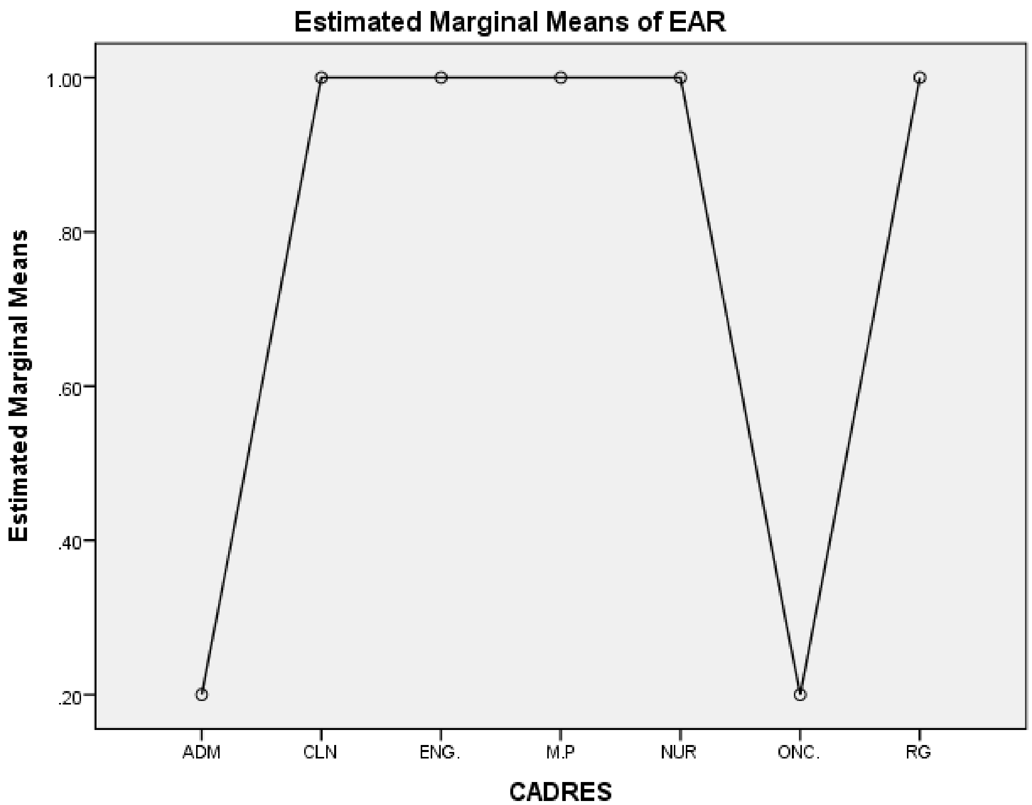

Figure 3. Radiotherapy Cadres with their Excess Absolute Risk (EAR) Model

To extensively discuss the provided conclusion regarding the relationship between Effective Annual Radiation (EAR) and Excess Relative Risk (ERR), and the associated cancer risk in various cadres as depicted in the figure, we need to delve into several key concepts: EAR, ERR, ADM, ONC, and the significance of the Beir VII report's recommendations [39].

EAR and ERR: Understanding the Inverse Relationship

The Effective Annual Radiation (EAR) and Excess Relative Risk (ERR) are both metrics used to assess the impact of radiation exposure on cancer risk. ERR is typically defined as the proportional increase in cancer incidence due to radiation exposure compared to a baseline (unexposed) population. It essentially measures the additional risk attributable to radiation [40].

On the other hand, EAR refers to the absolute increase in cancer cases per unit of population per year due to radiation exposure. While ERR gives a relative measure, EAR provides an absolute risk, making it more tangible in terms of the number of additional cancer cases expected annually[41].

ADM and ONC: Low Cancer Risk Cadres

The conclusion that "ADM and ONC exhibited the lowest cancer risk" suggests that individuals in these groups (presumably specific occupational or demographic cohorts) experienced significantly lower cancer incidence rates compared to other groups. Without specific definitions for ADM and ONC, we can infer that these groups have characteristics or engage in practices that reduce their exposure to harmful levels of radiation or perhaps benefit from protective factors [42]..

Other Cadres and High Cancer Risk

The statement "the remaining cadres showed the highest cancer risk" indicates that all other groups apart from ADM and ONC have higher incidences of cancer, likely due to higher radiation exposure or other risk factors. This emphasizes a differential risk distribution across various groups, which could be due to differences in occupational exposure, lifestyle factors, or inherent vulnerabilities [43].

Positive Values and the 30% Recommendation of Beir VII Report

The text states that "all the obtained values were positive," meaning that every assessed cadre had a measurable increase in cancer risk due to radiation exposure. These values being "significantly below the 30% recommendation outlined in the Beir VII report (2006)" refers to the guidelines provided by the National Research Council's BEIR (Biological Effects of Ionizing Radiation) VII Phase 2 report.

The BEIR VII report (2006) provides comprehensive risk estimates for cancer following low doses of ionizing radiation. The "30% recommendation" might refer to a specific threshold or risk limit considered acceptable or within safety margins. The fact that all values are significantly below this threshold indicates that, although there is an increased risk, it remains within acceptable bounds as per the BEIR VII guidelines [44].

Conclusion

For Radiotherapy medical cadres, the annual effective doses were determined to be 1.9132 mSv, with a collective annual effective dose of 80.41 person mSv. Among the Radiotherapy workers, 46.88% received an annual effective dose surpassing 1 mSv. None of the workers exceeded annual distribution ratios of 5, 10, and 15 mSv, and the lifetime cancer risk remained below 75%.

Recommendation

Given the widespread use of ionizing radiation in Radiotherapy, it is crucial to assess the occupational radiation exposure of the medical department at Usman Danfodiyo University Teaching Hospital. Based on the obtained results, the following recommendations are proposed:

i. Ensure the Harshaw 4500 manual TLD reader used in the study is consistently calibrated with a 137Cs beam exposure before each use.
ii. Conduct a similar study using the harshew automatic TLD reader 8800/6600 model for its enhanced precision and accuracy.
iii. Develop or upgrade models capable of detecting both ERR and EAR cancer risks simultaneously.
iv. Extend the assessment of occupational radiation exposure to workers beyond Radiotherapists, including Radiologists, Dental workers, and porters.
v. Implement affordable time-schedules to reduce workload on radiation workers, minimizing human errors.
vi. Construct models capable of detecting cancer at any radiosensitive organs. vii. Read the TLD after one month, considering Sokoto's temperature, to prevent chip fading.
vii. Increase staffing levels to alleviate workload in the departments.

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